1976

Alabama gully control handbook

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ALABAMA GULLY CONTROL HANDBOOK

by

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B.S.C.E., University of Mississippi, 1959

Presented in partial fulfillment of the

requirements for the degree of

Master of Resource Administration

UNIVERSITY OF MONTANA

1976

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TABLE OF CONTENTS

ILLUSTRATIONS

LIST OF TABLES

CHAPTER I

GULLYING--AN INTRODUCTION

Gullies come in a variety of sizes and shapes. All but the smallest are difficult to arrest. Although some people believe conversion to a garbage dump is a universal cure-all, there really are few effective, lasting remedies.

The contents of this chapter offer some insights on gullying in the belief that the remedy is easiest understood when the disease itself is clearly defined. Particular effort is made to concentrate on the problem as it exists in Alabama, especially in the Southern Coastal Plain where some of the country's most severe gullying is found. It is necessary to draw on information that was derived outside Alabama and the Coastal Plain because of the limited research interest in certain aspects--particularly the effectiveness of control efforts.

Rainfall Erosion and Gully Development

Erosion is not the product of a single causal force but rather of many. In all but a few very special cases, rainfall is the primary causal force of erosion in the southeast. It is complemented by the action of the sun, of temperature changes, of the wind, and of man and animal.

The energy spent in rainfall impact is considerable. According to a relationship developed by Wischmeier and Smith (1, p. 161), an acre-inch falling on the earth's surface in one hour imparts the effects of about 900 foot-tons on that surface. This is about the equivalent of one-third ton of TNT per square mile (2, p. 26), which in turn is a little more than the energy released by an earthquake having a magnitude of 3 on the Richter scale (3, p. 11). This, however, is but a fraction of the energy represented by the rainfall. An acre-inch weighs around 113 tons. Thus, each 10 feet downward it can move represents 1130 foot-tons of potential energy--more than the original impact energy by nearly 25 percent. Even from 300 feet above sea level, this is a lot of potential energy. Obviously it is not all used up in the erosion process. It is clear that there is plenty of energy available for this purpose, though.

It is at the impact of a raindrop that erosion starts. At that instant soil particles are loosened from the soil surface and splashed into the air. If the surface is level, the chances are pretty good that the soil particles will come back to rest somewhere near their original locations. If the ground is sloping, the particles may not stop for quite a while. The physical and chemical makeup of the soil largely controls the amount of soil that moves. The finest soils, those with much clay, resist the raindrop impacts rather well, but once the minute clay particles get detached they are easy to move. Conversely, larger sand-sized particlesare rather inert and are easily detached, but their sheer bulk makes them harder to transport. As a result of raindrop detachment, fine material and nutrients tend to move away, leaving what is sometimes termed an "erosion-pavement," an accumulation of coarser particles on the surface. (The wind can cause this same development.) (1, p. 163). Plant cover is the chief inhibitor of damage from raindrop detachment.

Sheet and Rill Erosion

Erosion has historically been described in three idealized categories based on the relative degree of scarring produced on the land surface. Two of these, sheet erosion and rill erosion, are really rather inseparable. Sheet erosion is described as uniform removal of thin layers of soil over extensive areas of sloping land as a result of uniform overland flow. Except under the most homogeneous of soil and surface conditions, this type of erosion will not likely exist in one area for very long. More often, minor differences in erosion resistance, surface irregularities, clumps of vegetation, or other obstacles cause minute flow channels to develop. So long as these channels or rivulets stay small and relatively indistinct, the erosion is considered sheet erosion. This is the type of erosion that gradually eats away at cultivated land, at inferior pastures, and at bare construction sites. Research information developed by the Agricultural Research Service in Mississippi suggests that in excess of 80 percent of Coastal Plain sediment which remains in transport is created by sheet erosion (4, pp. 100-103). This is primarily because only a small percentage of the land is involved in gullies. It points out the importance of good land use practices in minimizing sediment production.

When flow channels become well enough defined to be easily seen, rill erosion is considered to have developed. The definitions of sheet and rill erosion are very loose, but this usually poses no impasse. When the ground surface gets to looking rugged, all will generally agree that the rill stage has arrived. Under rill conditions deeper flow and higher velocities develop in the channels and tend to accelerate erosion. Rills will continue to grow unless altered mechanically, hampered by resistant material, or protected from water in some manner. So long as they are of such a size that routine farming manipulations will erase them rills are still so classified. When they reach some vague larger size, rills become gullies. Thus, rill enlargement is one way gullies can form.

It is significant to observe that even in a highly active gully, a major portion of soil removal is usually in rills and sheet erosion.

Gully Erosion

If a rill continues to grow, it eventually reaches such a depth that it is considered to be a gully. This depth is arbitrary, usually about three feet. But certainly "rills" shoulder deep have developed in a new earth fill slope in a season, so it is clear that time seems to creep into the obscure definitions of rill and gully.

Gully Forms

Various authorities recognize from two to half a dozen different gully forms. Two general types seem sufficient for the purpose of this discussion. One type can be thought of as flume-like, gradually increasing from zero depth and growing generally deeper and wider in a downstream direction, though not necessarily in a great degree. It may or may not have multiple fingers (rills) at its upper end. This form can only persist where soils are uniform and at least modestly resistant to erosion. Rilling may deteriorate into a network of flume-like gullies.

In lightly-cemented sediments, it is not unusual to see a narrow, flume-like gully two, three, or sometimes four times as deep as it is wide. However, width-depth relationships may vary erratically, even in the same gully.

Most severe gully problems in Alabama seem to be associated with what is usually termed a "head-cutting" gully. The head of such a gully is typically a vertical or overhanging drop-off or overfall. The most severe of these usually involve an inversion in erosion resistance--moderately resistant above slightly resistant soils.

An overfall typically starts when erosion works through resistant material and penetrates material of substantially less resistance. A vertical face forms (5, p. 174). The bottom gradient may be gentle, often much flatter than the soil surface adjacent to the gully. Since few soils possess strength to support a vertical face for long, the face tends to cave. Caving may progress upstream at rapid pace or at a snail's crawl. One new gully in Monroe County advanced over 150 feet in its first year of life. Of this advance, approximately 75 feet was during a single 15 inch rain in April, 1975. This gully had a drainage area of less than 15 acres.

Two factors seem predominant in the advance rate of head-cutting gullies--erodibility of the underlying soils and internal strength of the overlying soils.

Headcuts may develop for reasons other than inversion in erosion resistance. A soft pocket may cause a "blow hole" to form in a gully, and caving into this hole will lead to head cutting. Minor irregularities may lead to hydraulic accelerations sufficient to tear holes. A tree root crossing a gully is often sufficient disruption to cause an overfall to begin.

It must be made clear at this point that all gullies do not develop in the sheet erosion-rill erosion-gully sequence. Currently this sequence may be the exception rather than the rule in Alabama. Most of the major problem gullies of Alabama seem to spring from rapid deterioration of a dominant watercourse. Often it was originally a man-made watercourse. Roughly a half dozen factors may interact in a given situation to produce a chronic gully.

Climate

The two major climate factors in the interplay in Alabama erosion are rainfall and temperature. Annual rainfall amounts are relatively high across the state, ranging from an average of 64 inches at the coast to an average of about 54 inches at the northern tier of counties. An important north to south difference lies in the fact that the southern counties experience significantly higher intensities (inches per hour) of rainfall. The big, hard-falling raindrops of semi-tropical rains are highly effective in dislodging particles and provide an ample supply of water to transport particles away.

Temperature interacts in two different ways to promote water erosion. The high temperatures of summer keep surface soils dry. Sands and silts lacking a significant clay fraction may respond explosively when suddenly wetted, melting away like sugar.

At the opposite extreme, freezing and thawing acts adversely on most fine-grained soils (those containing significant silt and clay). Freezing seems to cause the water requirement of the soil to become unsatisfied, and moisture is drawn from below. This added moisture also freezes. When pore space becomes ice-filled, particles will become separated as added moisture is drawn up. Thawing leaves a loosened, soggy mass of soil (6, pp. 197-198). During the winter, soils may freeze and thaw almost daily in much of the northern part of the state. When rain comes, it finds loosened soil ready to be swept away.

Topography

It should suffice to simply state that steepness promotes rapid runoff. Rapid travel of water enables it to transport more soil per volume of runoff. The relief of an area has much influence on land use. The steepest land tends to get relegated to timber production, because it would fall apart if used otherwise. Thus, much gullying is on the margins of land sloping five percent or less.

Soil Type

It is readily observed that resistance of soils to erosion varies in a general way with clay content and fineness--higher clay content and finer soils are associated with erosion resistance. This relates to the fact that there are strong inter-particle forces between the clay-sized particles. (Various systems and authorities consider particles anywhere from 0.005 to 0.002 mm as clay, the difference being a little academic.) Larger particles seem to have little or no attraction for one another, though sizes through the finer sands are readily bound together by capillary tension, a water-pore space interaction.

Small percentages of clay can make sandy soil relatively resistant to erosion. In absence of clay or other cementing agents, there is a general decline in erosion resistance as particle sizes increase--up to a point. As particle sizes increase, weight of particles--and thus inertia--increases. In the gravel sizes (larger than about ¼ inch) inertia of individual particles is a significant factor in erosion resistance.

A previous section mentioned a relationship between fine soils and adverse freeze-thaw behavior. There is still another adverse behavior among the fine soils worthy of mention. This is shrink-swell, which relates to wetting and drying. Several types of true clay particles possess a unique structure which allows them to take on moisture and greatly increase their effective size. When they lose moisture, they shrink. This shrinkage causes cracking in masses of soil, a common sight in summer months. A sudden downpour can fill the cracks rapidly with water, which acts as a wedge. In a crack ten feet deep, there would be over one and one-half tons of force per foot of crack length. It is obvious that such a force would greatly assist in tumbling a block of soil off a steep bank.

Geology

Figure 1-1 shows the major physiographic or land resource areas of Alabama. Within each area surface soils share a similar geologic history and, to varying degrees, similar mineral composition. They also share similar topographic features. Because of these similarities there are also similar erosional characteristics.

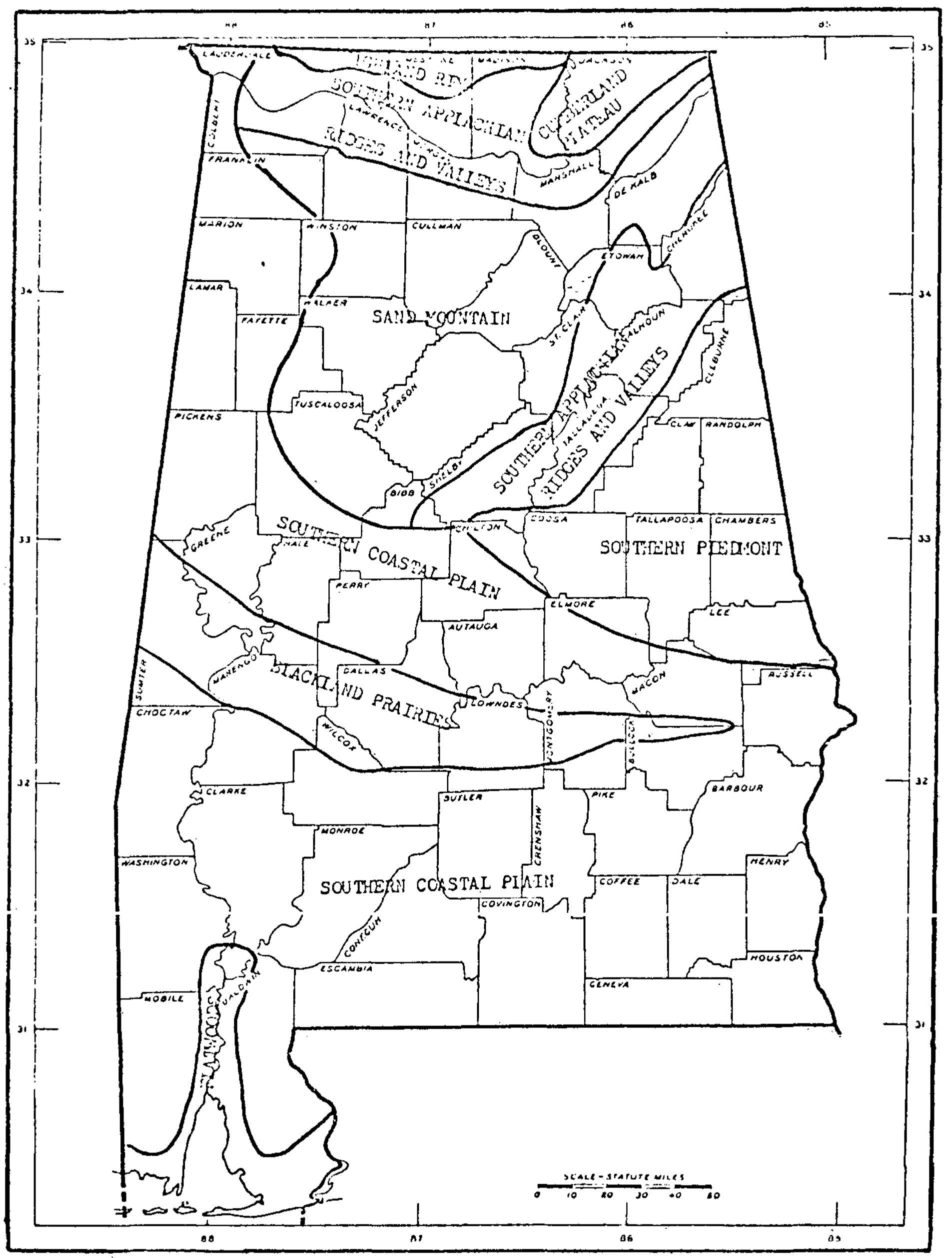
Highland Rim. This is a minor resource area in Alabama and tends to get included with the adjacent Ridge and Valley area. The upland soils derive from limestone and tend to be plastic and cohesive soils. Steepness contributes to erosion, but limestone at a shallow depth in many areas makes it difficult for major gullies to develop.

Cumberland Plateau. This area is limited to a fringe of Madison County and about half of Jackson County. Relief is rugged and gullies develop in the steep land in spite of plastic, moderately erosion-resistant soils. Gullies normally fail to develop much areal extent largely because of underlying limestone and already bisected topography.

Southern Appalachian Ridges and Valleys. Soils derive variously from limestones, shales, and sandstones. Some are very easily eroded because they possess only a minor fraction of binding

Figure 1-1. Major Land Resource Areas of Alabama.

ALABAMA



Source: U.S. Department of Agriculture, Soil Conservation Service, Land Resource Regions and Major Land Resource Areas of the United States.

material. Where these soils are deep some very significant gullies develop. Depth of soil above unweathered rock is generally the factor which limits such gullies.

Most soils in this area are moderately resistant to erosion, or are rugged and in timber, and this is not generally considered a major gully area.

Sand Mountain. Much of the surface material of the Sand Mountain area is highly erodible. Gullies have and do develop and have caused significant land damage. Shallow depth to sandstone or other parent rock sharply limits depth of gullying. Flat surface slope reduces runoff amount and rate, diminishing the erosion capability of runoff for much of the area. Rainfall tends to be a little less intense than in the southern part of the state. Erosion problems require more conservative treatment than in any physiographic area except the Coastal Plain--the main difference apparently relating to presence of bedrock and subtle rainfall variances. The fact that much of the upland is rugged and in timber also plays an important part in minimizing gullying.

Southern Piedmont. The upland soils are weathered primarily from schists, phylittes, gneisses, and granites. Mica influence is strong, and soils are generally less resistant to erosion than would be expected from the moderately plastic, cohesive behavior of the soil. Observation of the talus at the base of road cuts will convince the skeptic that freezing and thawing are important erosional forces in the Piedmont. Depth to rock-structured material tends to limit depth of gullies, though some very long, flume-like gullies are observed. They are usually on steep land, which makes stabilization difficult.

Blackland Prairies. Soils are typically much more plastic and cohesive than in most of the remainder of the state. Imprudent land use has lead to considerable shallow gullying. Healing is difficult because new vegetation cannot readily thrive in the sterile clay and chalk exposed by erosion. The presence of marl and chalk at shallow depth in upland locations inhibits growth of deep gullies, but branching gullies covering large areas have been allowed to develop in the past. Development is slow, but successful stabilization tends to be slow too.

Southern Coastal Plain. Approximately half of Alabama lies in the Coastal Plain. Soils vary considerably, but with minor exceptions surface soils are not highly plastic or cohesive. The soils are some of the most erodible in the country, and cultivation practices are some of the more conducive to erosion. The geologic combinations in much of the coastal plain are catastrophic. It is not uncommon to find 30 to 50 feet (vertically) of almost pure sand overlain by a thin mantle of moderately resistant soil. If underlying sand is penetrated by a watercourse, a head-cutting gully will race up-gradient. It is this type of geologic circumstance and similar ones that make active gullies, 30 to 70 feet deep, commonplace in the Coastal Plain.

The gullies of the Southern Coastal Plain are among the most difficult to stabilize of any in the country. They are perhaps the most difficult. Semi-tropical rainfall, the worst of soil conditions, and intensive farming couple together to create almost insoluble problems. The absence of geologic material which will assist in providing a stable gully floor at times makes the task seem futile.

Flatwoods. The soils have generally poor erosion resistance. Most support lush vegetative growth, which tends to inhibit gullying. However, lack of relief is probably the main element tending to minimize gullying.

Land Use

The harsh critic of man's "civilized" activity would like to credit man with inventing erosion and gullies, but it didn't happen that way. Many of the land forms that we appreciate--the rolling hills, the breath-taking canyons--are direct benefits of nature's sloppy but effective landscaping process labeled "erosion." What a conservationist labels criminal, an artist (subconsciously) labels saint.

It is a fact, though, that civilized man has made great strides toward perfecting the erosion process. A good generality is that the more intensively man uses land, the greater will be the potential for erosion damage. For example, measurement on runoff test plots in Missouri indicated removal of native cover. Intensively cropping land can increase gross runoff two or three-fold and peak runoff amounts by as much as ten-fold (7). Replacing native cover with pavement and roofs is even more drastic. As runoff increases, erosion must also increase unless protective measures are taken to compensate.

The vegetative cover type and the condition of the cover are factors upon which men intentionally or inadvertently exercise strong control. These two factors exert more control over runoff than most are aware of. Since the runoff is a primary tool of soil removal and is the almost exclusive means of transport in Alabama, it seems self-evident that the most effectual tool of erosion prevention and control is manipulation of vegetative cover. Not so strangely, the erosion control measures which fall under the heading of "correct land use and sound vegetative practices" reap cash rewards in better yields, conservation of fertilizer, and minimum land maintenance. Structural measures reap rewards only in the fact that they avoid (to varying degrees) the ultimate destruction or damaging of land resources.

The point of the last paragraph can best be emphasized by reference to gully behavior of southern Alabama. There are many gullies in south Alabama which became stable in the past without structures, simply because of improved land use and the decreased runoff which resulted. Current farming practices are reactivating some of these gullies.

It is tremendously important to keep sediment out of watercourses. A watercourse with healthy vegetation can become a gully overnight if a heavy deposit of sediment from careless land use engulfs it and smothers protective vegetation. This is sometimes the first phase of reactivation in a previously stabilized gully.

Chapter III deals in detail with the interaction of soil, cover, and topography in predicting runoff.

Mechanical Alterations

There are a few steps that man takes in his use of the land that have a remarkable influence on the amount of gullying experienced. Perhaps the most important of these is concentration of runoff into synthetic drainage patterns, speeding up the rate of water disposal from the land. When coupled with an increased amount of runoff, the effects are sometimes catastrophic. Most of the chronic, problem gullies in Alabama result from the overloading, in terms of velocity and volume, of a drainage-way.

The terrace is one of several effective methods of limiting sediment production from sloping, cultivated land. It is equally effective in concentrating water and causing erosion, unless it is properly outletted. Terraces have frequently been outletted over steep banks into highway ditches (often potential gullies even without aggravation) or even into active gullies. Without the safe outlet condition provided by broad, grassed disposal areas or retardation of flow supplied by underground pipe outlet systems, terraces can become vehicles of erosion instead of the preventatives.

Highways frequently alter patterns of natural drainage. Flow is concentrated to central points of disposal. The most difficult-to-control gullies in Alabama are those which develop at the outlets of highway culverts. It is not uncommon for a drainageway to degrade 20 to 30 feet at the outlet of a road culvert when the outlet impacts in highly erodible soils. In April of 1975 engineers of the Soil Conservation Service examined over 200 situations where such gullies endangered roads and other fixed improvements in 10 south Alabama counties. There were situations that had become lethal as the result of two large spring rains. The cost of either controlling these problems or repairing damages will amount to two or three million dollars. Such gullies are expensive and difficult to control because space is always limited and the situation is always at the emergency stage by the time remedial steps are taken.

Farm roads are a prominent cause of major gullies. Alignments that run at the steepest possible slope are the worst offenders. However, any road which doubles as a watercourse is a potential offender. Careful diversion and control of surface drainage are important in preventing such gullying. Improved surfacing in the form of gravel or the more costly surface materials pays good returns from a conservation standpoint but may be hard to sell from an economic standpoint.

Fences

Many of the gullies of south Alabama are the result of an old cow trail along a fence line. Various techniques will help prevent development of such gullies in the future. Among these are the planting of clumps of trees or shrubs along a downhill fence line, arbitrary "spur fences" or hedges at right angles to a downhill fence, and periodic placement of electric fences to allow vegetal recovery along fences. More important than any of these is a thoughtful grazing program.

Drainage Area

The size of the drainage area, or the catchment area as some prefer to call it, greatly affects the magnitude of a gully problem and the difficulty of treatment. Size is significant, because if all other factors are equal, total runoff volume increases in proportion to the size of the drainage area. Of course, factors which influence runoff are more likely to vary with size--soils, for example, or rainfall intensity. It still is factual that larger, more difficult gully problems are associated with larger drainage areas.

It is significant to note that diversion of runoff often has the net effect of decreasing the drainage area of one water course at the expense of another. The wisdom of such an action may be questionable.

Reactivation

By looking at aerial photographs taken over the past 30 years, one can ascertain that in a period before peanut and soybean production mushroomed in south Alabama, there were a good many gullies with a well-vegetated body and a raw headcut. They are wooded, or they have various kinds of viny growth, or they have bamboo, but they are no longer stable because of a more intensive use of the drainage area that allows more runoff. They were stabilized by "natural principles." These are gullies which for the most part were stabilized through concerted efforts of the Soil Conservation Service, companion agencies, and conservation-minded farmers who valued the future. These are disheartening situations to a career conservationist who has spent 30 years trying to get a job done only to see it wash away.

The Magnitude of the Gully Problem

There has not in recent times been an organized attempt to quantify gully problems in Alabama. However, there are two studies of gullying in the Southern Coastal Plain which give good insight for the southeastern one-sixth of the state. These are a planning evaluation for Southeast Choctawhatchee Watershed (8) and an inventory of erosion for the Wiregrass Resource Conservation and Development Area (9).

The Choctawhatchee study involved an on-the-ground evaluation of gullies identified from aerial photography and ground examination for a 167,000 acre area. This study identified 2,173 actively-damaging gullies (8). This is a frequency of one gully per 77 acres. A rough estimate in 1975 dollars is that it would cost $25,000,000 to stabilize these gullies.

The Wiregrass inventory, by sample count areas, estimated that there are nearly 30,000 gullies (9) in a nine county, 3.4 million acre area. This is a frequency of about one gully for every 113 acres. It has been observed that very few gullies are found in timbered areas other than at the fringes. Therefore, a better measure seems to be one which excludes timbered areas. On this basis there is an active gully for every 50 acres of non-timber, rural use (cropland, pasture, idle, etc.).

The Coastal Plain accounts for about 16.3 million acres of the state's 32.7 million acres. About one-third of this amount, or 5.5 million acres, lies in that portion of the Coastal Plain which is north of the Black Belt. That portion lying south of the Black Belt amounts to about 10.8 million acres. Approximately 28 percent of each of these subdivisions is in agricultural use other than timber production (10). Extending the rate of 50 acres of non-timber land per gully would indicate that there are about 60,000 gullies in the portion of the Coastal Plain south of the Black Belt. The fact that there is reasonable geologic similarity between southeast and southwest Alabama lends some degree of reasonability to this estimate. The inventory figures indicate that about 25 to 30 percent of the gullies would require structural measures in order to achieve stabilization.

The figure of 50 acres per gully does not apply to the Upper Coastal Plain. There are some significant gullies in this area, but it is doubtful that there are as many as 1,000 that would require engineering measures to achieve stabilization. This conclusion is based on casual observation of the area but is also supported by the fact that few stabilization structures have been reported by SCS offices in the area in recent years.

The same sort of observations lead to the conclusion that there may be fewer than 500 active problem gullies in the remainder of the state.

The volume of sediment produced in Alabama is very significant though the average rate of sediment production per square mile is not as large as for some other parts of the country. A recent U.S. Geological Survey report estimated that 7,900,000 tons of suspended sediment enters Mobile and Perdido Bays annually.[1] Most of this originates in Alabama, small portions of it originating in Mississippi, Georgia, and Florida. Only a small portion of Alabama is excluded from this estimate. The rate of sediment production in these areas ranged from 70 to 156 tons per square mile. It is obvious that not all of this is from gullies. It is likely that less than 10 percent of this sediment is from gullies.

Examples of Costs

The most obvious cost of gullying is the on-site land loss. There are less obvious on-site losses because gullies bisect land into less farmable units and compound the water disposal problems. However, the problem doesn't stop at the gully site. When a 20 foot deep gully grows an acre, it will release an estimated 16,000 to 20,000 cubic yards of soil, whose volume as loose sediment may

[1] This estimate includes several small Florida estuaries west of and including Wetappo Creek. Bed load would add about 10 percent to this estimate.

double its original in-place volume. The material will weigh 18,000 to 27,000 tons depending on the nature of the soil.

Whether the material stays in transport all the way to the ocean or is quickly re-deposited, its effects are not likely to be good. It snuffs out plant life if re-deposited on land and aquatic life if it remains in transport or is deposited in-stream. There are also off-site costs in keeping navigable streams open and in maintaining carrying capacity of upland waterways.

Figures from recent environmental impact statements will serve to underline the magnitude of the offsite costs. A statement concerning maintenance of 463 miles of navigation channel in the Tombigbee and Black Warrior systems reported that 2.2 million cubic yards of soil has to be removed and disposed of annually (12, p. 44). The report cited did not state costs; however, other sources give costs of $0.20 per cubic yard (13, pp. 2-5) to $1.10 per cubic yard (14, p. 2). Cost varies sharply with technique and location of the material, but overall cost is probably nearer the larger figure. Moving the sediment is not the total problem, however. Dredge spoil has to be put somewhere. This particular project requires transfer of 500 acres per year (12, p. 45) from private to government ownership for disposal sites and related purposes. When one considers that this involves non-replaceable bottom land hardwoods, a vanishing type, it becomes an even more ponderous cost.

According to another impact statement, 4.7 million tons of sediment are annually transported into Mobile Bay. About 1.4 million tons pass on through the estuary and are deposited outside the tidal inlet (13, p. 10). Annual maintenance removes 7,528,000 cubic yards of materials from channels at a cost of $1,535,000. Disposal affects 20,000 acres of bay bottom and 2,800 acres of gulf bottom. There are also 1,113 upland acres currently being utilized for spoil disposal (13, pp. 19-23).

These examples of maintenance cost are by no means isolated. They represent a fraction of the total cost of waterway maintenance in Alabama. They underline how costly erosion really is. In fact, they indicate that off-site costs may easily exceed on-site costs.

As the writer stood on the shore of Mobile Bay recently, crab fishing in its dark, turbid water, a description of the Bay that must have been written years ago came to mind. It described brilliant white sand beaches and clear, sparkling blue water. The description probably contained a lot of poetic exaggeration, but it still makes one wonder just what the cost of erosion has been in terms of natural beauty forever lost and what it will be in years to come.

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CHAPTER III

OVERVIEW OF METHODOLOGY

Man's struggle with gullies--his attempts to stabilize or heal the scars--is not a new one. It is not even unique to this country. It does, however, trace back to the very earliest days of the nation. In fact, Patrick Henry is quoted in an old USDA Farmer's Bulletin as relating patriotism with stabilizing gullies (1, p. 1).

In the early days of this country, when land was fairly plentiful, it was often expedient to simply move on to new ground when the land became depleted and gullied. That time is forever gone. The time has arrived when we must have virtually all of the productivity of our land. When the utility of land becomes restricted by gullying, the restriction if forever. Ironically, it is land that is highly capable of producing food and fiber that is most likely to be damaged.

It is no more important to prevent gullying now than it was a hundred years ago. The land damaged then was damaged forever. The only difference the hundred years have made is in the degree of urgency. This is much like death. Man knows almost from birth that he will someday die--in fact that he is dying by bits and chunks. But when he suddenly finds that he has cancer or heart disease, the matter of preservation of life, of going on living, becomes one of urgency. In this same sense, conservation of our land resources has suddenly become urgent--whether it be keeping land from being wasted in excessive power line rights-of-way, in frivolous shopping areas, in unneeded highways, or in hungry gullies.

The effective ways of stabilizing gullies are few, the number of possibilities diminishing drastically in the more complex situations. There are some gullies that it is either impossible or impractical to stabilize. This chapter attempts to give insight into the methodology and problems of gully stabilization. It deals with specific measures in generalities, treating structures in detail in Chapter IV.

Natural Stabilization

Natural healing of a gully is not totally unheard of in the southeast, but it does not happen with sufficient frequency to make it worthwhile to sit around and wait for one to heal.

In the areas of minor or shallow gullying, particularly in the Piedmont, simply allowing the land to lie idle and reforest itself has hidden many gullies. In most cases portions of a gully stay raw for years after a canopy develops. Then, eventually, trees and vines take hold. It was undoubtedly observation of such areas that led to some of the stabilizing techniques which have been successfully applied under more adverse circumstances. For example, it is readily observed that when a tree falls or is blown across or into a gully, soil will tend to catch, and that new seedlings can then get a foothold. Analogously, small brush dams have been successfully used to provide a foothold for pine seedlings.

In the chronic gully areas, particularly in the southern portion of the Coastal Plain, naturally stabilized gullies are rare. Most which approach being stable are that way due to intensive efforts. There are a good many semi-stable gullies whose body is stable or even aggrading a little, but whose head is gradually moving along. They tend to be in the more resistant soils.

In the few cases that have been noted by the writer where the whole gully was apparently static from natural causes, the gully body was surrounded by and in woods and the drainage area had experienced a drastic change in hydrologic condition due to a change in land use--from row crop to idle or hay land or woods. These gullies also tend to share in common the fact that, before reaching "stability," they have drastically reduced the area draining over their heads. Their floors are of material that is at least moderately resistant to erosion; none are pure sand.

There seem to be two important principles that are observed in natural (or accidental) stabilization of gullies. These are (1) provide a stable, suitable plant growth medium, and (2) reduce the amount of runoff below that amount which is causing gully growth. Though they don't solve all the problems, these two principles are important in many of the solutions to gully problems.

One further point seems worthy of emphasizing. Left to its own course the chances are much greater that a gully will advance completely to the head of its watershed than are the chances that it will heal naturally.

Vegetative Stabilization

This section is not an attempt at providing agronomic guidance. Rather, it is an attempt at establishing the relative import of vegetative stabilizing measures, and it is an attempt at showing where the the successes have been and, conversely, where the failures have been.

Vegetative stabilization is important for two reasons. First, there are many gullies that have been stabilized by vegetative means alone or with minor physical alterations. Many gullies with drainage areas less than twenty acres will respond favorably to intensive vegetative measures. There are sites with relatively low gradient, high permeability watersheds as large as 40 acres where perseverance and a little luck will result in stabilization by vegetation. When vegetative measures are successful, they are the least expensive way of treating a gully. The second reason vegetative methods are of great import is that practically all structural procedures lean very heavily on vegetative methods. Most structural methods aim at halting the linear advance of a gully. Vegetative techniques are necessary to stop erosion in the body of the gully.

Kudzu

Over the years a number of plants have been used, with a varying degree of success, in stabilizing gullies. Kudzu was once widely used in the southeast with good success. It will probably slow a gully's growth more quickly than any plant available. Yet, the plant is much more frequently maligned than praised. Without any pretense of charity, it seems appropriate to label this attitude as one borne out of inaccurate observations. The critic observes that, along highways or on somebody's (perhaps his own) farm, kudzu has climbed to the top of trees and literally engulfed them. The conclusion is quickly drawn that the woods are doomed. The fact is that unless the plant is killed back, it will gradually whittle away at the edge of the woods. It can quickly engulf a young pine plantation, but this is not so for a good stand of large trees. Its reach is limited. It does not tolerate shade well. Therefore, it can affect trees only within the limits of its runners on top of the trees.

The point that is often overlooked about kudzu is that it requires maintenance. It is not a particularly tough plant. It can be killed, for example, by overgrazing. It can be kept in its place with a minimum of effort using herbicides. The problem is not kudzu. It is people who don't maintain or who don't know how to maintain. It is the problem of SCS and sister agencies to get the right information out rather than standing around being "yes men" for the critics, as many have for the last 15 years.

Why this testimony for kudzu in a discussion really aimed at structural gully control? Because this country simply cannot afford to sink five to thirty-five thousand dollars each in stabilizing two or three hundred thousand gullies scattered over the southeast.

It is only fair to look at the disadvantages of kudzu briefly. It is certainly no cure-all. It does not always stay on the ground, and thus serious erosion may take place under the concealment of kudzu. It improves the land it covers, but it does not allow any other plant growth in the covered area, rendering the land completely non-productive from an economic viewpoint.

Pine Trees

There are various plants which have been used with some degree of success in gullies, but the plant which has the most of offer seems to be the pine tree. It does not take control as quickly as kudzu. However, it offers 365-day protection, while kudzu and many grasses may tend to lose their grasp during dormant periods. Research comparing various pines in loess and Coastal Plain soils of Mississippi and Tennessee indicate that Loblolly is probably the best stabilizer, because the volume of litter it produces is greater than for other varieties. The data indicated that Loblolly was only slightly better than slash (2, p. 45). Litter production seemed to correlate very closely to height attained in the 10-year test period. The second reason that pine trees are good gully plants is that they return some degree of economic productivity to the gully. Trees are hard to harvest without damaging stabilized areas, but limited harvest is possible.

Shaping and Grassing

Shaping-and-grassing is a process which converts a gully or a gully-head into a stable waterway. The gully is filled and shaped by bulldozing or blasting and machine grading to form a uniform waterway. The waterway is then grassed with a plant or plants best adapted to the soils and climate. Grass may be seeded or may be placed as sod. Some of the most successful installations have been those where sod was anchored with stakes and chicken wire, but the cost of material and labor has caused this procedure to be all but forgotten.

Shaping-and-grassing is normally limited to gullies which have small watershed areas and small overfall heights. Various sources suggest that maximum drainage area should be limited to 25 (1, p. 31) to 40 acres (3, p. 3). The probability of success diminishes rapidly when drainage exceeds twenty acres unless the drainage area is flat and pervious. If the waterway is in pure sand, 10 acres of watershed may prove too much.

One of the main keys to success in this procedure is to tie the waterway to stable conditions at its termination. A gully floor of raw sand is a guarantee of failure for a shaping job at the gully head. Stable outlet and unstable outlet conditions are discussed further in later sections of this chapter.

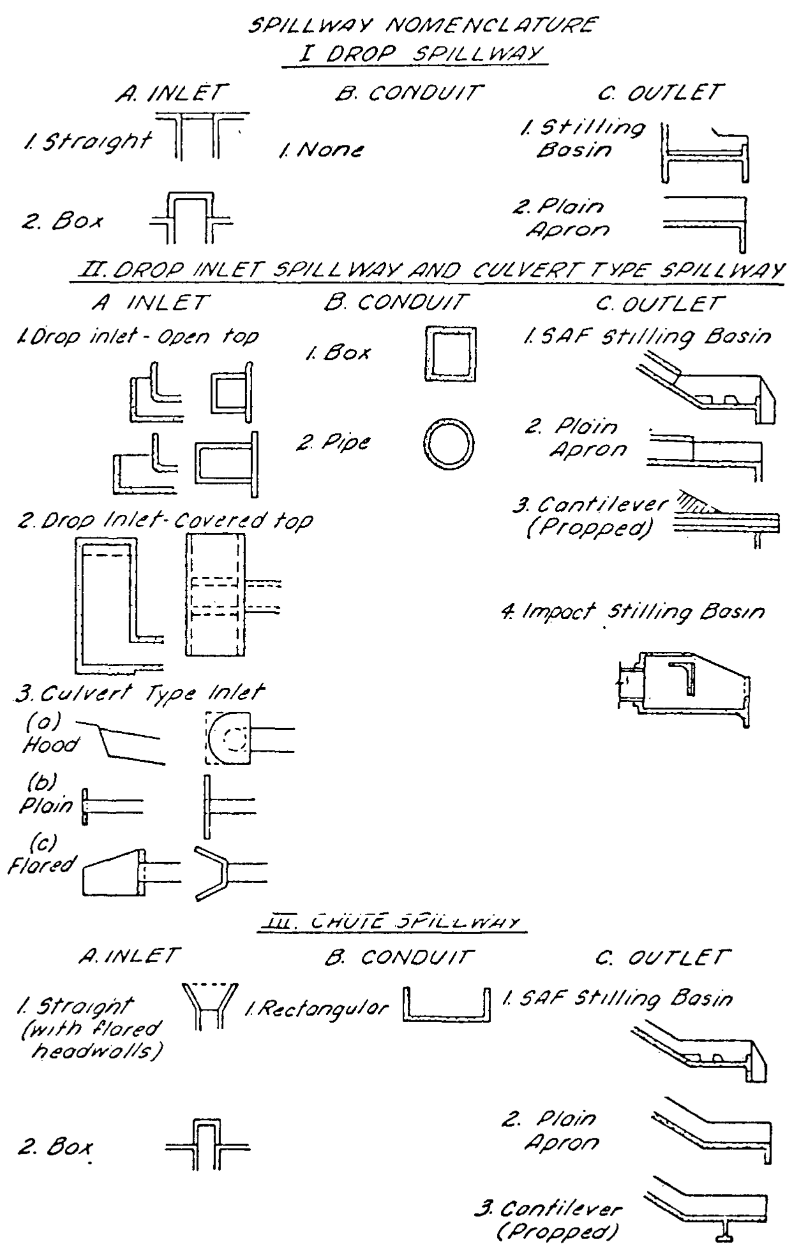
This is not a hit or miss procedure. The waterway must be so designed that erosive velocities will not develop, or there is little hope for success. Design criteria and design tools are included in Chapter 4.

It must be added that success depends very much on weather conditions in the few months following installation of the measure. It depends somewhat too on the land user's persistence in trying to make the measure work.

Structural Stabilization

Structures are rarely used alone as a means of stabilizing a gully. More commonly, they are used to arrest movement of a

Figure 2-1. Nomenclature for Inlet, Conduit and Outlet of Spillway.



Source: USDA, Soil Conservation Service, Engineering Field Manual for Conservation Practices, p. 6-5.

gully-head, trap sediment, control the gradient within a gully, or effect some combination of these. In a limited number of circumstances some structural measure alone will assure stabilization. An example of this is a gully with a timbered body but with a head moving into open crop land. Once the head is halted, the body may be able to heal naturally.

Structures are a last resort because they are expensive. A simple structure to control ten feet of head on a 20-acre drainage area may be expected to cost five to eight thousand dollars. If the head cut is thirty feet and the drainage area 100 acres, cost will be on the order of twenty-five to thirty-five thousand dollars (1975), depending upon complicating factors.

The structural measures used in gully control are in essence spillways. They are usually in some form of dam or dike. Structural measures are thought of as consisting of three functional components. These are the inlet, the conduit, and the outlet. Table 2-1 depicts the various components used and the terminology used to describe them.

The <u>inlet</u> is the point of entry of runoff. Its size and geometry control or radically affect the hydraulic capacity of the structure. Particularly in the case of drop inlet and culvert type inlets, specialized measures to enable the inlet to function in the presence of trash are important.

The conduit is the element which conducts water to the point of disposal. It may be open, as in a flume, or closed, as in a culvert pipe. It must rest on a substantial foundation, since minor settlement may lead to damage or destruction of the conduit.

The outlet is the crucial element of the structure. It must either dissipate or accomodate the effects of the energy imparted to the water in its fall from the inlet to the outlet.

The successful behavior of most outlet types is highly dependent on an exacting set of stable hydraulic conditions in the outlet channel below the structure. Unless these conditions can be maintained, the structure is very likely to self-destruct by undermining. This set of requirements effectively excludes rigid stilling basin and plain apron type outlets from consideration in most of Alabama's worst gully situations.

The cantilever type of outlet is susceptible to undermining but has found favor because it is easier to prop on long legs (piling).

Drop spillways and chute spillways are open-topped structures. They offer several pronounced advantages. They have little difficulty in handling trash in a wide variety of sizes, and there is always a variety of debris to be handled. They also handle large volumes of water efficiently. The drop spillways are adapted to relatively low heads. Chutes can be designed to accomodate high heads, though the design is very specialized, and requirements are very exacting.

A major limitation is that both types need to operate against tailwater, which is hard to maintain in an unstable gully floor. Without tailwater they are likely to destroy themselves by undermining.

There are many variations of drop inlet and culvert type spillways. Design variations in the inlets affect hydraulic efficiency and ability to handle debris. Variations in the conduit material affect cost and structure durability and, to a lesser degree, capacity. Variations in outlet support condition and impact area radically affect cost and structure stability against undermining. Most structures in this category are of corrugated metal pipe, a material bought primarily because of initial cost rather than long-range economy.

Figure 2-2 is a chart prepared as a guide for selecting the proper structure type for different hydraulic requirements. It was intended to reflect relative economies, which have changed somewhat over the past 15 years.[1] It is still a good guide tool, but it is not a decision tool.

The selection of the proper structure type has to be based first on functional considerations, then on relative economies. If the

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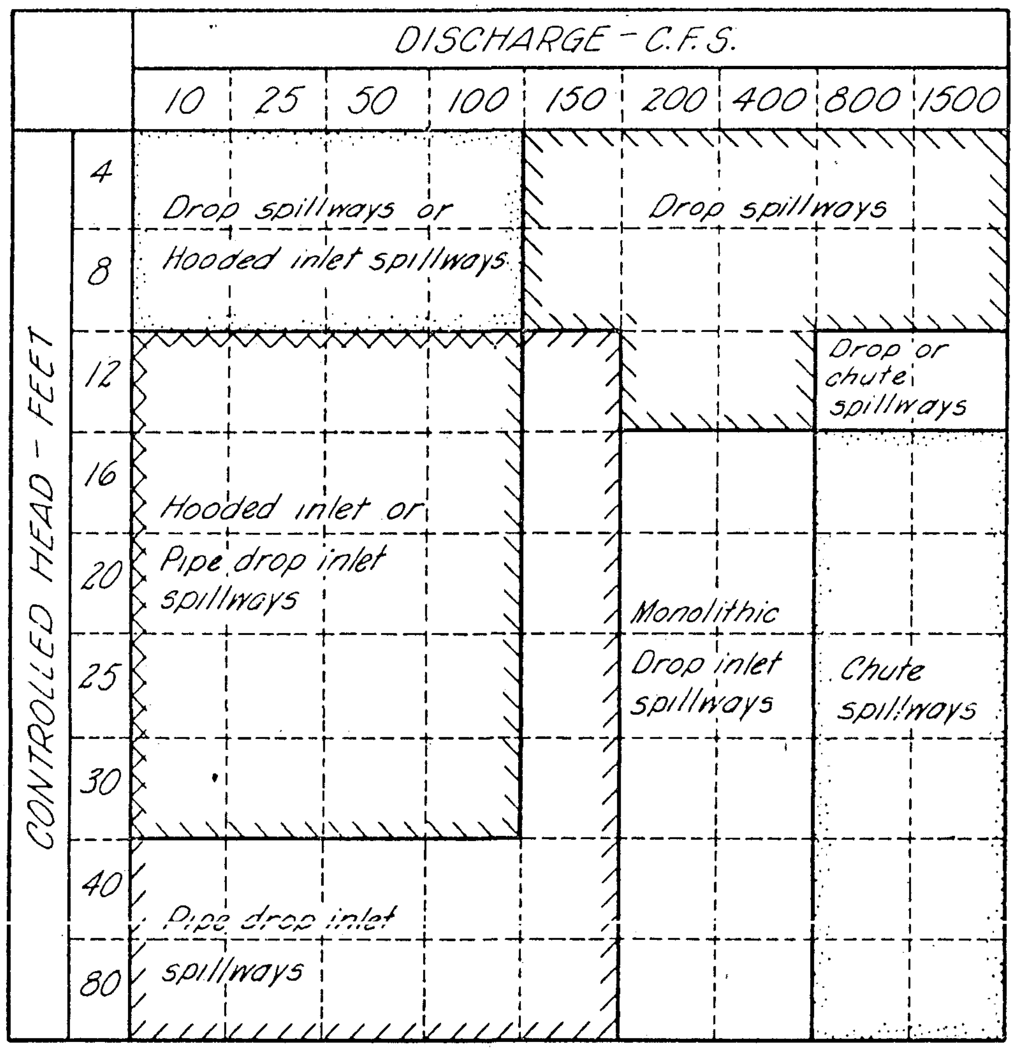
[1]Technological advances in the construction materials industry have been pronounced. For example, corrugated metal pipe used to be hand riveted. Now much of it is helically spun by machines that automatically weld or crimp seams. Such changes have put processes that require much high-priced hand labor, such as forming concrete, at a disadvantage.

Figure 2-2. General Guide to Structure Selection.



Note: Chart shows most economical structure as related to discharge and controlled head providing site conditions are adequate.

Source: U. S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices, p. 6-7.

structure cannot perform safely with a relatively long life, there is no point in considering it at all. If it seems that two types will do the job equally well, an estimate of cost based on current construction and material prices should serve as the basis for selection. It is not necessary to make precise cost studies in most cases. One type of structure will usually have a significantly favorable advantage over other possibilities. It is important to be sure that all major design problems are considered. It is also important to decide on relative structure life first and to make certain that alternatives have the same general life prospect. Otherwise, the comparison will be faulty.

Diversions

Diversion of flow around a gully is a very old technique for allowing vegetation to develop in a gully. In the southern portion of the Coastal Plain in Alabama it appears to have been highly unsuccessful. Where flow is diverted around a gully, it commonly causes one or more new gullies to form. There are many instances where diversions have been moved as many as a half a dozen times, each time creating a new head-cutting gully. Sometimes the old gullies do not stabilize but continue to gobble away at the land.

The problem is basic and simple. If water must get from a point of higher elevation to a point of much lower elevation and the two points are only a short distance apart, the water will be moving fast when it reaches the lower elevation. Fast-moving water is erosive.

Unless flow from a diversion can be safely carried by a waterway or natural water course at non-erosive velocities, there are but two apparent choices. Either a diversion should not be used, or, if diversion is utilized, a mechanical spillway of some type must be used to conduct flow safely to a lower level. If there are exceptions to this generality, they are few enough in number to make it frivolous to search them out.

It is much more likely that diversion without mechanical control will prove successful in portions of the state outside the Coastal Plain than within it. Even in these areas, careless application of diversions can be very damaging to the land.

Detention and Retention

Impoundments that store or detain large volumes of runoff offer an added dimension to gully control. Impounded water facilitates sedimentation. Material in transport can be made to settle out. This would seemingly produce downstream sediment reduction. Whether this materializes will depend on conditions downstream from the impoundment. The clean water may simply pick up a new load of sediment from the gully floor below the structure.

Desilting dams, as they are often called, have been used very little in Alabama. There is seldom a situation that facilitates the storage of a significant water volume at the head of a major gully, though a closed-end diversion may be used for this purpose. Even where the situation would allow storage, the water quality is poor and probably would not support fish. Without fish the impoundment becomes a menacing mosquito-breeding area.

Unless the storage capacity of an impoundment is very large relative to expected runoff, the effects of storage or detention probably should not be considered in determining outlet capacity. This is especially true if there is much active erosion above the structure. Sedimentation could reduce storage or detention to a level of ineffectiveness in a short time. When it appears that storage would have a long term value, reasonably reliable estimates of sediment volume can be made by techniques in the Soil Conservation Service's Technical Release No. 51, or by various simplified techniques available elsewhere.

There are rare locations where an entire gully or a large portion of one may be converted either into an impoundment or into a series of impoundments. Water storage may be a viable means of returning a gully to economic productivity. Three important factors have to be carefully evaluated. These are:

(1) Would inflow of sediment cause significant loss of

storage volume in a short period of time?

(2) Would pollutants, including sediment, herbicides, poisons, and animal wastes make it impossible to produce fish?

(3) Could the impoundment(s) be made to store water?

The last factor mentioned is often the controlling factor. In most of the Coastal Plain it is safe to assume that water cannot be impounded if seepage does not flow through the gully all of the year. Even then, if the gully walls are sand, loamy sand, or various non-plastic sand-gravel mixtures, there is little hope for impoundment.

Detention and retention concepts have found so little application in Alabama that they are not discussed further in Chapter IV.

Approaching the Solution to a Gully Problem

It has been obvious from the previous discussion that three factors define much of a gully problem's magnitude. These are size of drainage area, runoff volume, and gully depth. They have small effect on the details of the solution. These details tend to key on or relate to four factors--the surface soils (the materials exposed in the gully), the substrata, the water table, and the gully gradient.

Handling Surface Soil Problems

Surface soils, when defined as the soils exposed by the gully, are the soils which interact with other factors to determine the rate of gully advance. Very frequently it will be these soils that control the decision between using structural methods or shaping and vegetating a gully. It is sometimes possible to import soils that resist erosion well for top soiling a shaping job, but usually the soils that can be pushed in from the gully walls are the determinant. If they are highly erodible sands, the logical decision will most likely be to depend on structural methods to control the gully head.

Most gully head control measures include some form of earth embankment. Usually the material for the embankment comes directly from the gully walls or from similar materials in adjacent areas. When an embankment must be made of highly erodible soil, rigorous steps must be taken to exclude all outside runoff from the embankment. This is especially true for soils of the SW, SP, SM, and ML groups of the Unified Classification System. It pertains to many SC and CL soils. The GP and GW soils and other gravels with minor amounts of fines will not support vegetation, but they are inadequate dam materials for other reasons as well. When embankment height exceeds about 15 feet, definite measures will be required to collect and dispose of the runoff that falls on the slopes of the embankment if the embankment is of very poor non-plastic and low plasticity materials. Otherwise, deep rilling or gullying will develop on the embankment.

Top-soiling and capping with moderately plastic soils are two acceptable methods of improving chances of vegetative success on embankments made of low- or non-plastic soil. Depth of topsoil or plastic materials should be at least six inches to assure long term plant success. These are high risk techniques, however, and they should not be the only measures taken on embankments involving large investments or where no long-term maintenance is expected.

Continuous horizontal sod strips at three to five foot intervals will usually forestall development of major rills for several months. If the intervals between the sod strips are seeded during an appropriate planting season, the sod strips should last long enough for the seeded grass to take hold. Sod used in this manner will need an initial irrigation to keep it from drying immediately.

It is often desirable to break the slope of higher embankments with a berm. When the uninterrupted vertical interval exceeds 20 to 25 feet, it is hard to get grass started without rilling, even in relatively good soils. Berms designed as storage terraces help overcome this problem. In easily eroded soil the berm has to provide several feet of storage depth, because eroded material would soon fill a shallower depth. These berms need a pipe or flume as an outlet. The area drained is usually so small that hydrology and hydraulics do not control sizing of pipes for these terrace outlets. Hay mulch is commonly used in vegetation of embankments. When this material will be used, the hydraulic structure must be of a size that will not clog with loose hay. Normally, a diameter of 10 inches to one foot will serve this function. Capacity should, of course, be checked using criteria given in Chapter IV if there is any doubt.

There are available a number of man-made mulching and soil surface coating materials. None but asphalt emulsions have been used to a significant degree in erosion control work in Alabama (1975). Many of these products do a reasonably good job of holding the soil together until grass can get started. They fill a real need in many instances. They should be approached open-mindedly, if with caution, as they become more readily available.

The surface soils at the head of a gully often must serve as a waterway to conduct flow safely to a water control structure. It is usually beneficial, when a drop or hood inlet structure is used, to place the inlet lower than the gully rim. This provides a bowl of calmer water that protects the embankment from swirling water, and it helps load the hydraulic structure efficiently by putting substantial depth of water over the inlet. Care must be taken to design the waterway leading into this bowl in such a fashion that it will not erode; otherwise a new gully may start above the control structure.

Controlling the Water Table

The water table location has very much to do with the solution of a gully problem, whether a structural or a vegetative approach is used. It is important to see a gully during the spring months and determine whether the gully contains an active seepage area or to determine this from one who knows. Failure to anticipate active seepage can be rather perplexing if a structural solution is used. It also can lead to failure of a shaping and vegetation job. If a shaping job is done on top of a seepage area, it is safe to assume that the fill dirt will not seal the seepage. Unless the fill dirt is quite plastic, it can be predicted that seepage will surface in the shaped area. This can be prevented by installing an under-drainage system consisting of a graded sand-gravel collection system and a perforated pipe disposal system. If fill depth over this will exceed five or six feet, cement-asbestos pipe is necessary. Corrugated plastic pipe will serve adequately for only light loading. Unless the seepage is controlled, there will be a vegetative failure or vegetative weakness in the area where seepage surfaces. A new head cut can be expected to develop from this point.

It would be highly desirable when a cantilever outlet is used to excavate a basin to serve as an energy dissipator. This would probably have to be rock lined. However, the presence of the water table near to or above the gully floor usually frustrates any such attempt. Where the lower walls and floor of a gully are sand and the water table is above the floor, it can be predicted that each cubic yard which is excavated from the floor will be replaced by an equal amount slumping from the walls. This problem is not so severe if the floor width is significant--say 50 feet or more, but it is still present. There are ways to advance excavation below the gully floor--installing sheet piling or installing elaborate well-point dewatering systems--but the available techniques are so expensive that they would disproportionately increase structure cost. Short of these techniques, one improvisation has worked modestly well in providing an armored impact area in below-water-table situations. Riprap has been positioned with a clamshell bucket and allowed to sink in the soft gully floor. It typically sinks a few feet and stops. Systematic placement will result in a relatively uniform bottom in the impact area.

When there is seepage from the walls and bottom of a gully, there is an inclination among designers to put a drain in the toe of an embankment structure contacting the seepage. If the embankment is of relatively impervious material and the seepage layer is not completely capped by the embankment, the embankment will cause the seepage to detour. The water bearing material will function as its own drain. If the structure is not one that impounds water for a long period, the hazard from piping is minimal in such a case. However, it is commonly necessary to install a drainage system in order to have a dry enough foundation to allow construction of a satisfactory embankment.

When the gully floor is below the water table, it is often impossible to achieve good compaction on the first material placed in the gully. It is sometimes difficult to get a firm enough footing to even run a dozer over.[2] This, plus the high compressibility of the gully floor, makes it imperative that the structure placed on it be designed to accommodate vertical movement. This requires long, special joints in concrete pipe; long, connecting bands in corrugated metal pipe; and similar movement-tolerant features in other structures.

Influence of the Gully Floor

Substrata, or material lying in and beneath the floor of a gully, will determine what happens within the gully after structures have

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[2]This is not intended as an unqualified endorsement of the practice of "walking in" a relatively uncompacted floor to work from, which is a poor practice. It is simply a recognition of the fact that it is not possible to do a thorough job of compaction against a soft, wet foundation. "Mopping" the foundation with dry dirt avoids much of this problem.

been installed. If these materials are erosion-resistant, a structure at the gully head may lead to rapid stabilization. If they are highly erodible, a gully-head structure may only be a stop-gap. Investigation of the material in and beneath the gully floor is one of the most important steps in deciding how to attempt stabilization.

It is particularly important to know what is under the floor of the gully in the vicinity where water from a control structure will impact. There are many gullies that bottom in tough, shale-like material that resists erosion well. Knowledge that this material extends thirty feet below the gully floor can reduce structure cost substantially. Conversely, knowledge that there are thirty feet of pure sand in the impact area may dictate founding a structure on deep piling.

It is not just the conditions at the area of water impact that are crucial. It is the conditions in the gully floor all the way to a nebulous point downstream referred to as a "point of stable grade." There are several sets of conditions that provide "stable grade." An outcrop of erosion-resistant material is perhaps the most desirable. This may be highly cemented soil material, shale, or rock. Stable grade may simply be a portion of the water course where vegetation has erosion under control. Stable grade may be identifiable only as an area of very flat gradient in the gully floor. Stable grade is often taken as the point where the gully joins a much larger drainage area, rendering flow from the gully relatively insignificant. There are many gullies on small drainage areas where the gully body is more or less stabilized near the head but the head remains active. When stable grade such as this is near at hand, the fixing is made much easier.

Knowing where a point of stable grade lies is important because it is predictable that as soon as a gully-head structure cuts off the major supply of sediment, the clearer water passing through the gully will tend to load itself with sediment from the gully floor. This will cause the gully to degrade. It often leads to the undermining of gully-head structures. When it is expected that degradation will be appreciable, the outlet structure is supported on deep piling to make undermining more difficult. If the distance and elevation between structure and stable grade are great, it may be necessary to use one or more intermediate structures in the body of the gully. Subsequent paragraphs concerning gully gradient will deal with intermediate structures and with depth of protection against undermining.

Ideally, a complete gully control job would stop all erosion and prevent degradation of the gully body. The preceding paragraphs obviously are not talking entirely in terms of this ideal solution. The individual land user's personal economics may limit what he can do, or what he is willing to do, to simply stopping the headward movement while relying on natural processes to control the gully body vegetatively. This may be completely successful and very likely will be if the floor of the gully is not extremely erodible material. If it is extremely erodible, something more will be needed. In no case are results instantaneous. In either case considerable degradation may occur before the gully becomes stable.

There are many instances where a single land user does not have legal access to enough of a gully to bring it under control without much degradation taking place. He may, in fact, have just become victim of the gully because his downstream neighbor declined to do anything about it. When several ownerships are involved in a gully, and all are not interested in solving the problem, compromises are often necessary. It may only be possible to set a structure on piles and hope the piling is deep enough to prevent undermining. There are semi-rational approaches to predicting how deep this should be.

Figure 2-3 illustrates a method for determining depth of piling needed for a structure founded in an unstable gully floor. The symbols are as follows:

s_p = the present average gradient (ft/ft) to a stable point

s_u = the ultimate average gradient (ft/ft) to a stable point

d_s = distance (ft) from piling to stable point

h_r = the required length (ft) of piling to be driven into the

Figure 2-3. Determining Required Depth of Piling.

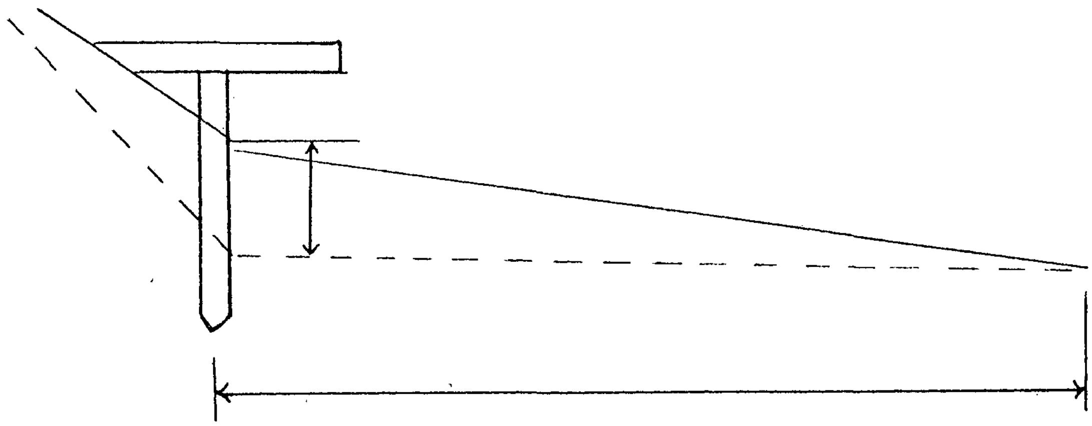
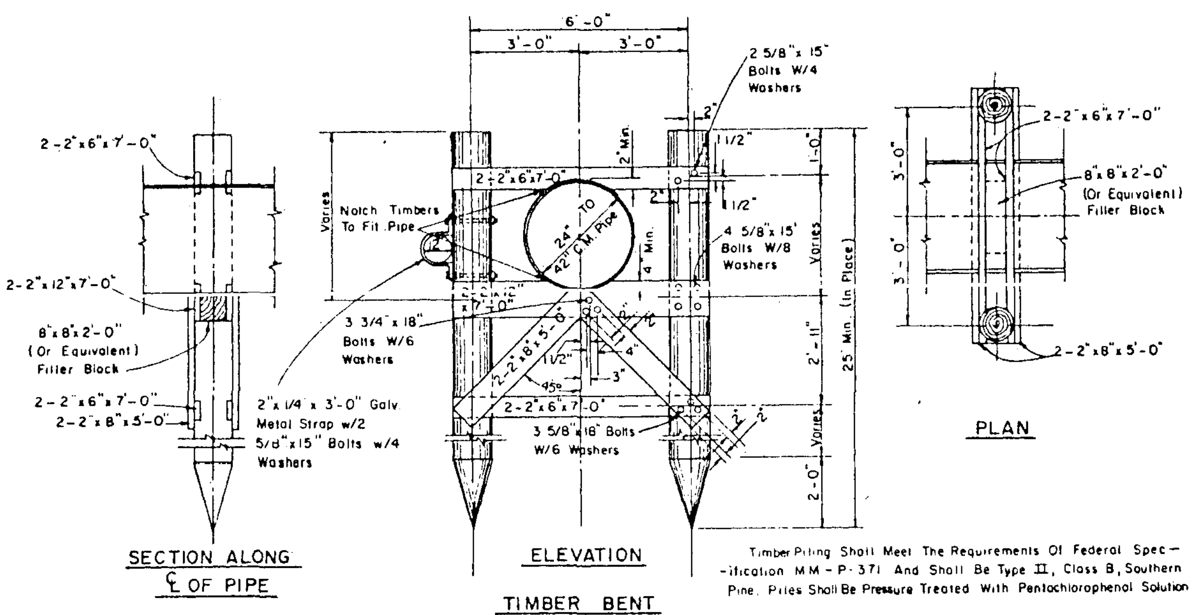


Illustration of a Timber Bent.



gully floor. Any amount required above ground must be added to h_r.

Simple geometry leads to formula 2-1 below:

$$h_r = d_s (s_p - s_u). \qquad (2-1)$$

Formula 2-1 is simple enough, but determining values for s_u and d_s is less straightforward. A previous paragraph discussed determining where stable grade exists. There is always a degree of uncertainty in this process. Evaluation of s_u is even less comfortable. There are several approaches.[3]

Observation of the floor gradient of nearby gullies which have become stable is an obvious and sound approach if carefully done. First, it must be ascertained that the prototype is really stable. Short term observations on this point may be misleading. It must also be determined that the geology of the gully floors is similar. It must be determined what accounts for stability of the prototype and whether this can be repeated in the problem gully. Finally, the drainage area of the prototype should be at least as large as that of the problem and in similar cover. This final condition may be impossible to satisfy.

A second approach is to rely on more generalized observations.

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[3]It is not usually practical to drive wood piling more than 20 or 25 feet in the Coastal Plain. Using this value range for h_r, it is possible to use formula 2-1 to determine where an intermediate downstream structure should be located.

It has been observed that on drainage areas up to 100 acres, very sandy cohesionless gully floors will usually stop degrading at gradients of one to two percent (ft/100 ft). Cohesive or cemented soils will perform better than this. This has led to frequent use of $s_u = 0.01$ ft/ft as a design value.

Still a third approach is to use tractive force theories to predict stable gradient. Tractive force is numerically equal to the total friction force resisting flow. It is taken as a measure of the shear forces which pick up and move soil along a waterway. Tractive force theory as applied by Soil Conservation Service is described in SCS Technical Release 25 (4).

$$T_{LB} = 0.4\, D_{75} \qquad (2\text{-}2)$$

$$T = F\, \gamma_w\, d\, s_t \qquad (2\text{-}3)$$

$$s_t = \left(\frac{n_t}{n}\right)^2 s_e \qquad (2\text{-}4)$$

$$n_f = \frac{D_{75}^{1/6}}{39} \qquad (2\text{-}5)$$

Formulas 2-2 through 2-5 are from Technical Release No. 25.

Terms are as follow:

T_{LB} = empirically determined allowable tractive force on the bottom of a waterway (p.s.f.)

T = theoretical tractive force on the waterway bottom (p.s.f.)

F = a factor which varies for 0 to 1 as the ratio of width to depth increases from 0 to infinity

γ_w = unit weight of water, 62.4 p.c.f.

d = flow depth in waterway(feet)

s_t = unit rate of head loss because of tractive force (ft/ft)

n_c = Manning's coefficient of roughness for waterway

s_e = slope of the energy gradient (ft/ft)

D_{75} = particle size which 75 percent of bed material is finer than (inches)

By substitution it can be shown that:

$$s_e = \frac{9.75\ (D_{75})^{2/3}\ n^2}{F \cdot d} \qquad (2\text{-}6)$$

The value of s_e should be very nearly the same as s_u in the formula 2-1. In reality, values determined by the formula are much flatter gradients than those normally experienced in gullies. The original derivations were based on rather coarse material having a D_{75} size larger than 0.25 inch. The technical release does not advocate using the methodology on finer materials except by correlation.

Direct use of formula 2-6 is not recommended, because it seems to be overly conservative. It does appear that it can be usefully applied in relating experience data to design situations. In this way it may even be possible to extend data from gullies having dissimilar bottom material.

Road Culvert Gullying

The gullies which develop at the outlet end of road culverts often offer "opportunities" unsurpassed by any other aspect of gully control work. It is quite common for such a gully to reach the outlet end of a culvert and lie there semi-dormant for several years. During this time, maintenance crews and "public-spirited citizens" may take notice and "feed the gully." The "food" will have a variety of attributes, some good and some bad. The diet includes soil, brush, garbage, old cars, construction trash, demolition rubble, dead animals, and an occasional wife and/or traveling salesman. Some of the materials (mainly concrete rubble) have good stabilizing attributes. Most offer poor aesthetics. Then the "storm of storms" comes along and the road culvert, or the road, starts falling into the gully. During its period of dormancy the gully may have reached a depth of 40 or 50 feet. At this point, several years too late, the cost of treatment may have doubled or tripled what it would have been when the gully had not yet reached the road. Solutions are difficult and involve a high risk.

If the drainage area is small, it may be possible to fill a portion of the gully with compacted earthfill and install a chute or flume. Some consider it bad engineering practice to place such structures on fill material, but very satisfactory installations are possible using this technique. Failure of the structures involves no high risk. An overly cautious position on this question is hard to defend. Design velocities will almost always be above super-critical.

Careless or unknowledgeable construction can lead to failure of these structures. An irregularity in the bottom due to settlement, expansion joint filler, or sloppy workmanship may cause cavitation that will eat away at the structure. Irregularities could also make the water jump out of the structure and undermine it. Therefore, designers tend to be cautious with such measures, limiting total head (fall) to as little as 15 feet and capacity to less than 100 cubic feet per second.

The more typical solution to road culvert gullying has two major parts. These are control of local road water, the water entering from the downstream side of the road, and control of water passing through the culvert. The local water can usually be handled with flumes. The flume referred to here is commonly called a "paved ditch" in the highway engineering field. The culvert water can be handled in two general ways. If the culvert is in good condition, it may be desirable to connect an additional culvert directly to it and carry the water to the gully bottom using 90- or 45- degree elbows to deliver the water to the gully floor and then re-direct it horizontally. A small, grated drop inlet can be used to get flume water into the culvert. The other alternative is to spill the culvert into a flume which conducts culvert and flume water to a drop inlet or hooded inlet structure placed at a slightly lower elevation. Either option requires a substantial amount of fill to bury pipe and, in the second alternate, to form a dam.

These two solutions each have certain advantages and certain disadvantages. Culverts are usually hydraulically inefficient and require larger conductors of flow. A careful study to make sure pressure flow will not develop is needed before the "additional culvert" alternate is used. Thrust blocks or very strong connectors at the elbows are prudent devices, even if pressure flow won't develop. This type of system does not require much skilled workmanship, which has led to its use by various county road departments.

Corrugated metal pipe installations of this type have experienced a high mortality rate due to use of short, flimsy connecting bands.

The flume-drop inlet installation has the advantage of creating some degree of hydraulic efficiency. Water is impounded in a small bowl area which facilitates quick hydraulic priming. Pressure flow is developed, and smaller hydraulic elements are needed than in the culvert alternative. There is one disadvantage. Unless the dam is nearly as high as the top of the culvert, the flume may shoot water right over the top of the dam.

There is one concealed problem at road culvert gullies. Upon first appraisal of the situation, one tends to jump to the conclusion that hydraulic capacity of the culvert controls the capacity requirements of the remedial measure. In other words, it is assumed that there is no need to provide a greater capacity in the remedy than the culvert will carry. This assumption may be erroneous. If a large storm can exceed the culvert capacity, the road will be overtopped. This could be disastrous to the gully control structure. The possibility may greatly complicate the solution to a road culvert gully problem. The water from an overtopping road may be hard to capture and contain without damage to the control structure.

Land Line Gullies

Cow trails along fences, cattle lanes, line ditches, and field roads have all caused gullies to develop on property lines. Regardless of the cause, many such gullies have a dimension common in only a small percentage of other gullies. Any solution to the problem requires cooperation of two land owners.

Sometimes one party will bear all the costs and take all of the initiative. Sometimes there is disagreement as to who should pay. Three areas of consideration may be helpful in deciding on a fair solution to such a disagreement: how the gully formed, when the gully formed, and who will benefit from the solution. The combinations of circumstances are infinite.

A good policy for the professional conservationist to adopt is one of not being an arbitrator in disputes such as this. He may, however, in good conscience help develop facts on relative benefits to be expected from the solution.

Deteriorated Road Ditches

There are hundreds of miles of badly eroded roadside ditches in Alabama (5). Until recent years, little sustained effort was made toward stabilizing these drainageways when roads were built. This was especially true for lower quality roads. Some of these roadside ditches take on dimensions of a gully and literally devour the road. Polish researchers discussing similar problems that exist in Poland accidentally coined a most fitting expression when they concluded it is necessary to "cancel" the road in order to stabilize the gullies (6). At the same time they expressed the sentiments of many who have encountered the problem. When there is a badly damaged road paralleled by a pair of hungry gullies (or even a single one), stopping the gully would be made a lot cheaper by "cancelling" the road. It wouldn't do much for the traffic problem, though.

It is possible to heal many roadside gullies with a minimum of earthwork and vegetative measures, but configuration of the highway side slopes often severely limits the possibilities. It would normally be desirable to construct a broad-bottomed waterway in order to help keep velocities low, but the narrow areas sometimes available in deep road cuts do not provide enough space. Velocities have to be kept relatively low in order to develop vegetation.

Velocity criteria are given in Chapter IV. If velocity limits cannot be satisfied, a vegetative approach should not be used.

Other factors may influence the decision of whether or not to use a vegetative approach. Sediment is one of the worst enemies of a vegetated waterway. If there is considerable active erosion present in the watershed, the low velocities specified for ditches and waterways are likely to cause sediment deposition of sufficient magnitude to damage vegetation. Then there is, once again, danger of erosion in the waterway. Therefore, the condition of road banks and adjacent land will have a definite influence on the decision whether or not to use a vegetative approach.

If the decision is made that vegetation alone will not suffice, there is little choice but to carry flow downhill in either an open or closed structure. If a closed structure is used a series of small drop inlets must be used to collect local runoff. Water may be carried to the inlets in properly-designed, grassed waterways, a combination of allowable velocities and expected inflow controlling spacing between inlets. The conduit must be sized to prevent pressure flow, or water may actually discharge from a downhill inlet. This calls for large conduits and often causes a flume (paved ditch) to be selected instead.

Flumes are not foolproof solutions to any problem. It is often necessary to first fill a roadside gully with soil before a flume can be installed. Placing a flume on fresh fill dirt makes it an even more risky venture than it would have otherwise been. A high percentage of the flumes which fail do so because loosely-placed fill dirt beneath the flumes settles away from them. This allows them to be undermined by runoff waters. Compaction of the fill dirt beneath flumes is imperative. The logical final step before fine grading the soil and setting concrete forms is to traverse the entire flume foundation with several passes of a mechanical tamper.

Highways are often built on steep gradients--steep relative to hydraulic considerations. This induces high velocities. Without a straight alignment, the water may climb out of a flume. Weeds growing in an expansion joint of a small highway flume have been observed to cause water to jump several feet into the air, landing outside the flume because of a curve.

It is usually desirable to limit drainage areas for flumes to about 40 acres. Larger areas will dictate very special design consideration. Terminating a flume is sometimes a touchy problem. Flumes are usually continued to an area of very flat gradient, often to the main drainageway in the valley. In these surroundings it has proven satisfactory to steepen the flume gradient and bury the end of it several feet deeper than the bottom of the primary drainageway. Alternatives to this include various types of lined stilling basins whose costs are usually out of proportion with the benefits they provide.

Maintaining Gully Structures

Installation of a structure to stabilize a gully should not be considered an act of finality. Frequent inspections are essential. An undermined flume can be saved by pumping grout under it if it is caught early; but in a few months an un-reinforced flume will break into pieces from undermining.

Much deterioration observed in gully control works is deterioration of vegetation and subsequent erosion damage. The soil material in and around gully control measures is usually the very poorest. Without regular fertilization, vegetation is often doomed to failure.

Shading is the very worst enemy of a grassed embankment. Very early, the decision should be made to either plant trees on the embankment or to protect it from shading. The natural transition from grass to trees may be so slow and spotty that severe damage will develop. Therefore, plant selection to assure shade-tolerant grass is important when a transition to trees is planned.

If there is no dedication to maintenance on the part of the land user or someone who can be counted upon, most efforts at stabilizing gullies will prove to be a waste of time and energy.

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CHAPTER III

HYDROLOGY

Small hydraulic structures of the types used in gully control are usually designed to handle the peak, or maximum, rate of runoff that can be expected from a rainfall event having a specific duration and volume. The procedure used for estimating peak rates of runoff was developed from study of rainfall and runoff data for small watersheds and is considered to be limited in applicability to watersheds smaller than 2000 acres, watersheds with average surface slope flatter than 30 percent, and to peak rates of discharge smaller than 2000 c.f.s. (1, p. 1). These conditions are normally satisfied with a safe margin by Alabama gully problems. The procedure consists of selecting a rainfall amount, evaluating important watershed runoff-influencing characteristics--area, slope, soils, and vegetation--and determining the peak runoff rate from charts.

Rainfall

The minimum rainfall amount that is normally considered for design purposes by the Soil Conservation Service is the 10-year, 24 hour rainfall amounts by county for Alabama.

The 10-year, 24 hour storm is considered as a minimum. If failure of a structure would be very costly either in terms of structure price or property damage, a larger rainfall amount may be justifiable. For example, if failure would let a major highway tumble into the gully, the 25 or 30 year storm would seem justified. The person or persons financing a structure should be aware of this aspect of design, and their desire should be honored to the extent that it does not violate sound design practice. Some will want more safety to protect their investment.

Drainage Area

Drainage area is best taken from aerial photography, which is available in all SCS field offices. It can also be taken from published soil survey maps or from U.S. Geological Survey topographic maps. The latter present information at scale that makes it impossible to depend on them for smaller drainage areas.

The procedure of trying to estimate drainage by visual inspection is generally inadequate. Spot examinations of SCS work have located instances where such estimates were in error by as much as 100 percent.

Both northern and southern Alabama contain sinkhole or "grady pond" areas. If a sinkhole receives enough seepage that it stays full or overflowing for at least 30 continuous days in an

Table 3-1. Expected 24-hour Rainfall Accumulation in Inches for Various Occurrence Frequencies.

County	1 Year	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year
AREA I							
Colbert	3.3	3.9	4.9	5.6	6.3	7.0	7.6
Cullman	3.4	3.9	5.0	5.8	6.6	7.2	8.0
Franklin	3.3	3.9	5.0	5.7	6.5	7.1	7.8
Jackson	3.3	3.8	4.7	5.4	6.2	6.8	7.5
Lauderdale	3.3	3.8	4.8	5.5	6.3	6.9	7.5
Lawrence	3.3	3.9	4.9	5.6	6.4	7.0	7.6
Limestone	3.3	3.8	4.8	5.5	6.3	6.9	7.5
Madison	3.3	3.8	4.8	5.5	6.2	6.9	7.5
Marshall	3.3	3.9	4.9	5.6	6.4	7.0	7.7
Morgan	3.3	3.8	4.9	5.6	6.4	7.0	7.6
Winston	3.4	3.9	5.0	5.8	6.6	7.2	8.0
AREA II							
Blount	3.4	3.9	5.0	5.8	6.6	7.3	8.0
Calhoun	3.4	3.9	5.1	5.8	6.7	7.4	8.2
Cherokee	3.3	3.8	4.9	5.8	6.5	7.3	7.8
Clay	3.5	4.1	5.2	6.1	7.0	7.7	8.5
Chambers	3.5	4.1	5.3	6.2	7.1	7.8	8.6
Cleburne	3.4	3.9	5.0	5.8	6.7	7.5	8.1
DeKalb	3.3	3.8	4.8	5.6	6.3	7.0	7.5
Etowah	3.4	3.9	5.0	5.7	6.6	7.2	8.0
Randolph	3.4	4.0	5.1	5.9	6.7	7.5	8.4
St. Clair	3.4	4.0	5.1	5.9	6.7	7.5	8.0
Talladega	3.5	4.2	5.3	6.2	7.0	7.7	8.2
AREA III							
Bibb	3.6	4.4	5.5	6.4	7.3	8.0	8.8
Greene	3.7	4.5	5.5	6.5	7.5	8.7	9.0
Hale	3.7	4.5	5.6	6.2	7.6	8.2	9.0
Fayette	3.5	4.1	5.2	6.0	6.8	7.5	8.3
Jefferson	3.5	4.1	5.2	6.1	6.9	7.6	8.4
Lamar	3.5	4.1	5.2	6.0	6.9	7.6	8.3
Marion	3.4	3.9	5.0	5.8	6.7	7.3	8.0
Pickens	3.6	4.3	5.4	6.3	7.2	7.9	8.7

Table 3-1 (Continued)

County	1 Year	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year
Shelby	3.5	4.2	5.4	6.2	7.1	7.8	8.6
Sumter	3.7	4.6	5.7	6.7	7.7	8.5	9.3
Tuscaloosa	3.6	4.3	5.4	6.3	7.1	7.8	8.6
Walker	3.5	4.0	5.1	5.9	6.8	7.5	8.2
AREA IV							
Bullock	3.7	4.5	5.8	6.7	7.8	8.6	9.5
Autauga	3.7	4.5	5.7	6.6	7.6	8.4	9.2
Dallas	3.8	4.6	5.8	6.8	7.9	8.7	9.5
Chilton	3.6	4.4	5.6	6.2	7.4	8.1	8.9
Coosa	3.6	4.3	5.5	6.4	7.2	8.0	8.8
Elmore	3.6	4.4	5.6	6.5	7.5	8.3	9.0
Lee	3.5	4.2	5.4	6.3	7.3	8.0	8.9
Lowndes	3.8	4.6	5.9	6.9	7.9	8.8	10.0
Macon	3.6	4.4	5.6	6.5	7.6	8.3	9.0
Montgomery	3.8	4.6	5.8	6.7	7.8	8.7	9.7
Perry	3.7	4.5	5.7	6.6	7.6	8.4	9.1
Tallapoosa	3.6	4.2	5.4	6.3	7.3	7.9	8.8
AREA V							
Barbour	3.7	4.5	5.8	6.8	8.0	8.8	9.5
Butler	3.9	4.8	6.3	7.3	8.5	9.4	10.4
Coffee	3.9	4.9	6.4	7.4	8.9	9.7	10.6
Covington	4.2	5.2	6.7	7.9	9.4	10.5	11.0
Crenshaw	3.9	4.8	6.2	7.2	8.4	9.4	10.0
Dale	3.9	4.8	6.2	7.2	8.5	9.5	10.4
Geneva	4.0	5.0	6.5	7.6	9.0	10.1	11.0
Henry	3.8	4.6	6.0	7.0	8.3	9.0	10.0
Houston	3.9	4.8	6.3	7.4	8.7	9.5	10.5
Pike	3.8	4.7	6.0	6.9	8.2	9.0	9.9
Russell	3.6	4.3	5.5	6.5	7.5	8.2	8.9
AREA VI							
Baldwin	5.0	6.0	7.8	9.3	10.4	11.6	13.0
Choctaw	3.8	4.7	6.1	7.0	8.0	9.0	10.0
Clarke	4.0	4.9	6.5	7.5	8.6	9.7	10.8

Table 3-1 (Continued)

County	1 Year	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year
Conecuh	4.0	5.0	6.6	7.8	9.0	10.2	11.0
Escambia	4.5	5.5	7.2	8.4	9.6	11.2	12.0
Marengo	3.8	4.7	5.9	6.8	7.9	8.8	9.6
Mobile	4.7	5.8	7.6	9.0	10.4	11.5	12.7
Monroe	4.0	5.0	6.5	7.7	8.8	10.0	11.0
Washington	4.0	5.0	6.7	7.7	8.9	10.2	11.0
Wilcox	3.9	4.8	6.0	7.0	8.2	9.0	10.0

Source: U. S. Department of Commerce, Weather Bureau, Weather Bureau Technical Paper 40.

average year, it is necessary to consider it as a contributing drainage area. If it dewaters quickly after rains to a level where it can contain the water that falls directly on it from a 50-year, 24-hour rain, it can be considered a non-contributing area. Intermediate or uncertain situations should be handled by techniques discussed in a subsequent section.

Soil-Cover Complexes

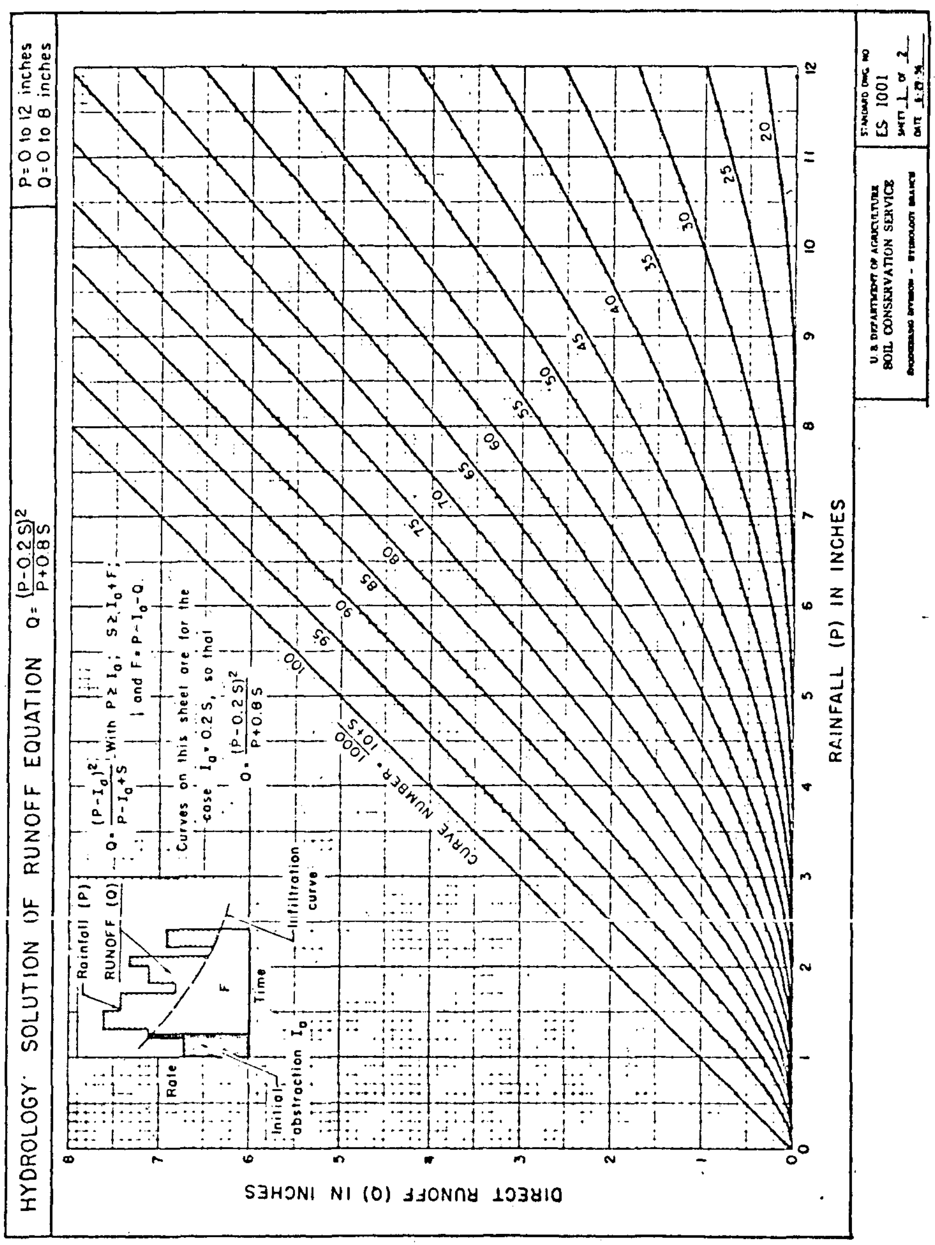
The soil-cover complex concept is the tool developed by SCS to predict total runoff due to rainfall. It combines the effects of soils and of vegetative cover. The operation of the concept consists of first grouping watershed soils according to the runoff-producing character of the bare soil. Then the effects of cover are combined by assigning an index number that is indicative of a particular soils having a specific type and quality of cover. The index number, called the Curve Number (CN), is used as the keying parameter to relate runoff and rainfall through a family of curves. A detailed explanation of this concept may be found in references 1 and 2. Figure 3-1 shows the general relationships between rainfall, runoff, and Curve Number (CN).

Rating of soils according to runoff production is relatively simple. Soils are rated A, B, C, or D, according to their relative runoff production. Runoff is highest on D soil, lowest on A soil. All of the named surface soils in Alabama have been rated in this respect. The most recent listing of these is presented in Table 3-2. Persons outside SCS must either consult SCS, secure data from published soil surveys, or make their own estimate.

It is possible for any person who has a fair knowledge of soil textures to do a reasonably good job of estimating hydrologic soil groups from the following brief guides.

> Group A soils are those with the lowest runoff potential. The rate of infiltration for these soils is high even when they are thoroughly wetted. They are primarily sands and gravels containing only small amounts of fines. They have good internal drainage, lacking plow pans or similar restrictions to flow at shallow depths below their surface.

Figure 3-1. Relationship Between Rainfall, Runoff, and Curve Numbers.



Source: U. S. Department of Agriculture, Soil Conservation Service, A Method for Estimating Volume and Rate of Runoff in Small Watersheds, SCS-TP-149 (1968), p. 5.

Group B soils produce more runoff per unit of rainfall than do Group A soils. They possess moderate infiltration rates when they are thoroughly wetted. They range from moderately fine texture to moderately coarse texture. Most of these have a predominance of sand in their makeup and contain little clay, if any. They generally lack flow restrictions of marked significance, though some plow pan development or similar structure may be present.

Group C soils are high runoff producers. They become quickly wetted in a humid region such as Alabama, and thereafter their rate of infiltration is low. They may be either the moderately fine to fine-grained soils or they may possess layers which restrict infiltration. They tend to have significant clay content though not in sufficient quantity or of the mineral make-up to make them greasy or very sticky.

Group D soils are soils with very slow infiltration rates after thorough wetting. They are clay soils or soils with shallow restrictions to infiltration such as a clay pan or impervious rock. Many of these soils develop wide cracks during dry weather due to the nature of the clay they contain. They are often very sticky or greasy feeling when wetted (2, p. 71).

Table 3-2. Hydrologic Soil Groups For Alabama.

Alaga	A	Captina	C	Duplin	C
Albany	C	Carnegie	C	Durham	B
Albertville	C	Cartecay	C	Edgemont	B
Aloca	B	Catalpa	C	Egam	C
Allen	B	Cecil	B	Emory	B
Altavista	C	Chandler	B	Enders	C
Americus	A	Chastain	D	Ennis	B
Amite	B	Chattahoochee	B	Escambia	C
Angie	C	Chenneby	C	Esto	C
Anniston	B	Chesterfield	B	Etowah	B
Apison	B	Chewacla	C	Eustis	A
Appling	B	Chipley	C	Eutaw	D
Ardilla	C	Christian	B	Exum	C
Atkins	D	Choccolocco	B	Faceville	B
Atmore	D	Clarkesville	B	Fairhope	C
Augusta	C	Colbert	D	Falaya	C
Aycock	B	Colfax	C	Fannin	B
Barbourville	B	Conasauga	C	Flint	C
Barth	C	Congaree	B	Flomaton	A
Basin	C	Cowarts	C	Forestdale	D
Baxter	B	Coxville	D	Freemanville	B
Bayboro	D	Craven	C	Fullerton	B
Benndale	B	Crossville	B	Fuquay	B
Bibb	D	Cumberland	B	Garner	D
Binnsville	D	Cuthbert	C	Geiger	D
Bladen	D	Davidson	B	Georgeville	B
Blaney	B	Decatur	B	Gilead	C
Blanton	A	DeKalb	B	Goldsboro	C
Bodine	B	Dellrose	B	Grady	D
Boswell	D	Demopolis	D	Grasmere	B
Bowie	B	Dewey	B	Greendale	B
Bradley	B	Dickson	C	Greenville	B
Brewton	C	Dierks	B	Grover	B
Bruno	A	Doravan	D	Guin	A
Buncombe	A	Dothan	B	Gunter	A
Byars	D	Dowellton	D	Guthrie	D
Cahaba	B	Ducker	B	Gwinnett	B
Camp	B	Dulac	C	Hamblen	C
Cane	C	Dunbar	D	Hanceville	B
Capshaw	C	Dunning	D	Harleston	C

Table 3-2 (Continued)

Hartsells	B	Leeper	D	Musella	B
Hayesville	B	Lehew	C	Muskingum	C
Hector	D	Leonoir	D	Myatt	D
Helena	C	Leon	C	Newark	C
Henderson	D	Lindside	C	Nolichucky	B
Herndon	D	Linker	B	Norfolk	B
Hiwassee	B	Litz	C	Ochlockonee	B
Hoffman	C	Lloyd	B	Ocilla	C
Hollywood	D	Lobelville	C	Okenee	D
Holston	B	Locust	C	Oktibbeha	D
Houlka	D	Louisa	B	Ora	C
Houston	D	Louisburg	B	Orangeburg	B
Hulett	B	Lucedale	B	Osier	D
Humphreys	B	Lucy	A	Pace	B
Huntington	B	Luverne	C	Pacolet	B
Huxford	C	Lynchburg	C	Pansey	D
Hyde	D	Macon	D	Paraloma	C
Iredell	D	Madison	B	Pearman	C
Irvington	C	Magnolia	B	Pelham	D
Iuka	C	Mallory	C	Pheba	C
Izagora	C	Mantachie	C	Philco	C
Jefferson	B	Marietta	C	Pine Flat	B
Johns	B	Marlboro	B	Pinson	B
Johnsburg	C	Masada	B	Plummer	D
Johnston	D	Mashulaville	D	Poarch	B
Kalmia	B	Maury	B	Ponzer	D
Kaufman	D	Maxton	B	Pope	B
Kenansville	A	Mayhew	D	Portsmouth	D
Kershaw	A	McLaurin	B	Pottsville	D
Kipling	D	McQueen	C	Prader	D
Kirvin	C	Melvin	D	Prentiss	C
Klej	B	Mecklenburg	C	Purdy	D
Lakeland	A	Mimosa	C	Rains	D
Lakewood	A	Minvale	B	Ramsey	D
Lauderdale	B	Molena	A	Rarden	C
Lawrence	C	Monongahela	C	Red Bay	B
Leadvale	C	Montevallo	D	Roanoke	D
Leaf	D	Mora Bey	D	Robertsdale	C
Lee	D	Mountainburg	C	Robertsville	D
Leefield	C	Muse	B	Rumford	B

Table 3-2 (Continued)

Ruston	B	Swain	C	Urbo	D
Rutlege	D	Sylacauga	D	Vaiden	D
Sacul	D	Taft	C	Vance	C
Saffell	B	Talbott	C	Varina	C
Sango	C	Talladega	C	Vaucluse	C
Savannah	C	Tallapoosa	C	Wagram	A
Sawyer	C	Tarklin	C	Wahee	D
Scranton	D	Tate	B	Warne	D
Seneca	B	Tatum	B	Waugh	C
Sequatchie	B	Tellico	B	Watauga	B
Sequoia	C	Tifton	B	Watsonia	D
Shubuta	C	Tilden	C	Waynesboro	B
Starr	B	Tilsit	C	Wedowee	D
Staser	B	Toccoa	B	Wehadkee	D
State	B	Tombigbee	A	West Point	D
Stendell	C	Townley	C	Wickham	B
Stough	C	Trinity	D	Wicksburg	B
Sumter	C	Troup	A	Wilcox	D
Sunsweet	C	Tupelo	D	Wilkes	C
St. Johns	D	Tuscumbia	D	Wolftever	C
St. Lucie	A	Tyler	C	Worsham	D
Susquehanna	D	Una	D	York	C

Source: U.S. Department of Agriculture, Soil Conservation Service, Alabama Engineering Field Manual for Conservation Practices, Auburn, Alabama (1972), pp. 2.5-2.6.

Once the soil type is determined, it is necessary to determine the vegetative cover and its condition. Hydrologically good vegetative conditions generally consist of complete plant cover and/or heavy litter. Mechanical runoff inhibition such as terracing and contour farming must be taken into consideration. These factors are reflected in a runoff curve number (CN) from Tables 3-3 and 3-4.

When several kinds of soil or cover are involved, a weighted average is determined using formula 3-1:

$$CN = \frac{A_1N_1 + A_2N_2 \; . \; . \; . \; .A_nN_n}{A_1 + A_2 \; . \; . \; .A_n} \qquad (3\text{-}1)$$

The values of A_n in the formula are the areas which combine to make the total for the watershed. The values of N_n are the runoff curve numbers for these areas.

It is obvious that rainfall history for a period of days preceding a storm event has influence on runoff produced by the storm. This rainfall is accounted for in the system as Antecedent Moisture Condition, abbreviated AMC. Three antecedent conditions are used. They are described as follows:

AMC I Lowest runoff potential. Soils in the watershed are dry enough for satisfactory cultivation.

AMC II The average condition.

AMC III Highest runoff potential. Soils are practically saturated from prior rains (1, p. 7).

Condition II is the condition normally assumed for design. It is the condition implied in the runoff curve numbers of Tables 3-3 and 3-4.

Surface Slope

The surface slope of the land has little to do with infiltration

Table 3-3. Runoff Curve Numbers for Hydrologic Soil-cover Complexes (Antecedent Moisture Condition II, and $I_a = 0.2\ S$).

Land Use and Treatment or Practice	Hydrologic Condition	Hydrologic Soil Group A	B	C	D
Fallow					
Straight row..............	----	77	86	91	94
Row Crops					
Straight row..............	Poor	72	81	88	91
Straight row..............	Good	67	78	85	89
Contoured................	Poor	70	79	84	88
Contoured................	Good	65	75	82	86
Contoured and terraced....	Poor	66	74	80	82
Contoured and terraced....	Good	62	71	78	81
Small Grain					
Straight row..............	Poor	65	76	84	88
Straight row..............	Good	63	75	83	87
Contoured	Poor	63	74	82	85
Contoured	Good	61	73	81	84
Contoured and terraced	Poor	61	72	79	82
Contoured and terraced	Good	59	70	78	81
Close-seeded legumes or Rotation meadow					
Straight row..............	Poor	66	77	85	89
Straight row..............	Good	58	72	81	85
Contoured	Poor	64	75	83	85
Contoured	Good	55	69	78	83
Contoured and terraced	Poor	63	73	80	83
Contoured and terraced	Good	51	67	76	80
Pasture or range					
No mechanical treatment...	Poor	68	79	86	89
No mechanical treatment...	Fair	49	69	79	84
No mechanical treatment...	Good	39	61	74	80
Contoured................	Poor	47	67	81	88
Contoured................	Fair	25	59	75	83
Contoured................	Good	6	35	70	79

Table 3-3 (Continued).

Land Use and Treatment or Practice	Hydrologic Condition	Hydrologic Soil Group A	B	C	D
Meadow	Good	30	58	71	78
Woods	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	25	55	70	77
Farmsteads.............	----	59	74	82	86
Roads					
Dirt....................	----	72	82	87	89
Hard Surface...........	----	74	84	90	92

Source: U.S. Department of Agriculture, Soil Conservation Service, National Engineering Handbook, Section 4 - Hydrology. Revised, 1972. p. 9.2.

but much to do with the rate of overland travel of runoff. It is necessary to know the average surface slope of the watershed in order to use the curves which give peak rate of runoff.

The slope which is needed is the weighted or average slope that runoff traverses enroute to the structure. To be precisely correct in determining this, a grid would be superimposed on a map of the watershed. The slope at each grid intersection would then be determined and an average value determined (1, p. 11). This technique may be a little rigorous, but it is far superior to sloppy guesswork.

Table 3-4. Runoff Curve Numbers (CN's) Urban Areas--Development Completed and Vegetation Established.

Description	Hydrologic Soil Group A	B	C	D
Lawns, Parks, Golf Courses, Cemeteries, etc.	39	61	74	80
Pavement and Roofs--Commercial and Business Areas	98	98	98	98
Row Houses, Town Houses, and Residential with Lot sizes 1/8 acre or less	80	85	90	95
Residential				
Lot Sizes of 1/4 acre	61	75	83	87
Lot Sizes of 1/2 acre	53	70	80	85
Lot Sizes of 1 acre	50	68	79	84
Lot Sizes of 2 acres	47	66	77	81

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 2 80.

The modern published soil surveys include approximate slope data. The weighting procedure illustrated in formula 3-1 can be used to determine weighted slope just as it was for curve number.

An adequate field method is to divide the watershed into segments having different apparent slope on an aerial photograph. Then a hand level or an Abney level is used to determine slope within each segment. Several determinations are needed per segment. Then the weighting procedure previously discussed is used to determine the average slope.

Peak Runoff Rate

Except in the case of very large hydraulic structures such as a power dam, it is impractical to make a detailed enough study to construct hydrographs that more than roughly approximate site conditions. Normally, it is necessary to generalize runoff-causing parameters such as rainfall distribution, watershed shape, infiltration, etc.

The Soil Conservation Service has created a family of curves which give peak rate of runoff as a function of drainage area, watershed soil characteristics, steepness and rainfall. A definite set of watershed shape characteristics is built in, as is a pattern of rainfall accumulation. The pattern of rainfall accumulation within the storm period which closely fits the pattern typical to most of the country is called a Type II storm (1).

When the four reference parameters--slope, runoff curve number, rainfall, and drainage area--are determined, figures 3-2 through 3-22 may be consulted to determine an appropriate peak runoff rate for design use.

In developing peak discharge curves, the assumptions in Table 3-5 were observed.

Figure 3-2. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

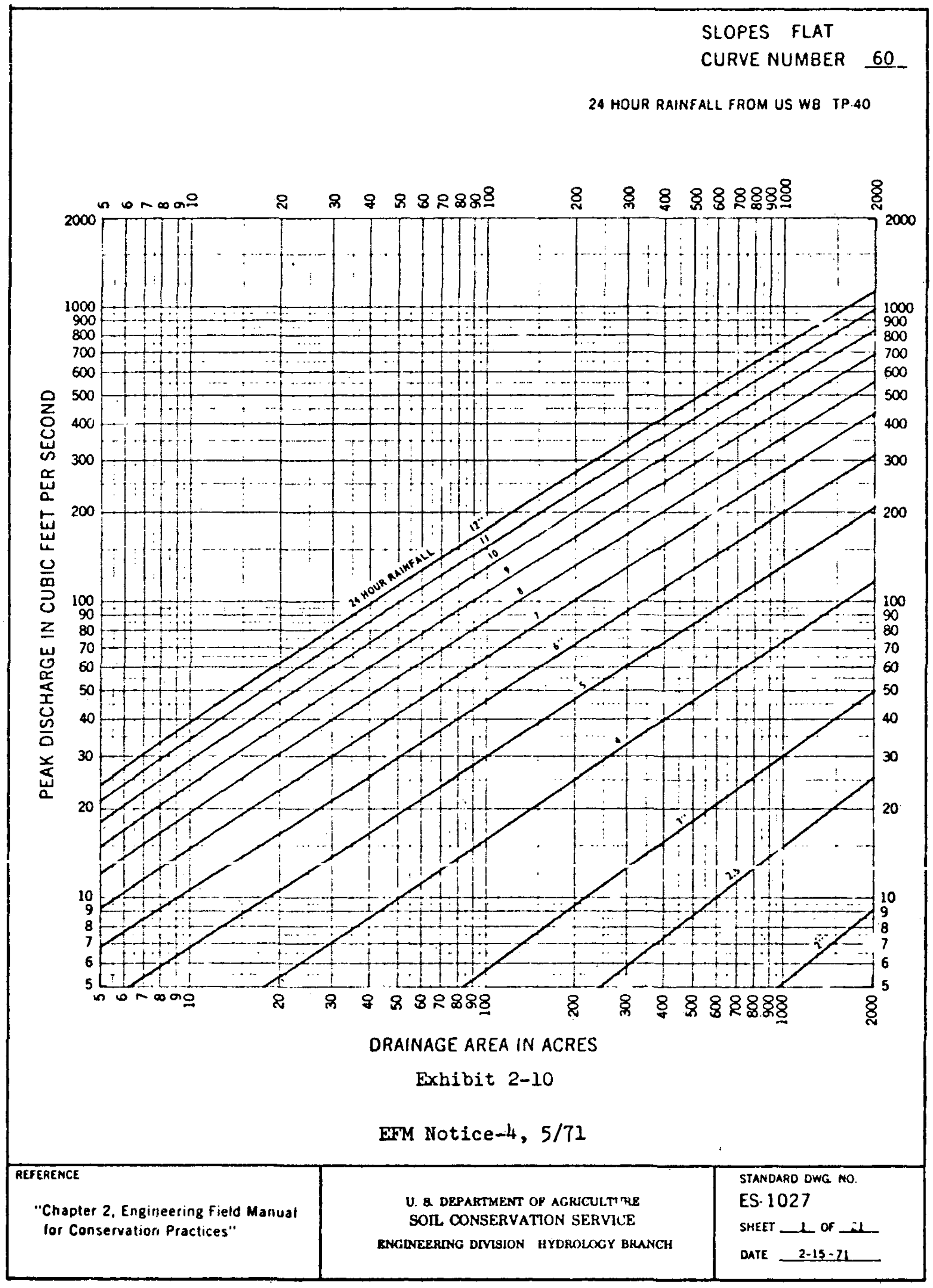


Figure 3-3. Peak Rates of Discharge for Small Watersheds Type II Storm Distribution.

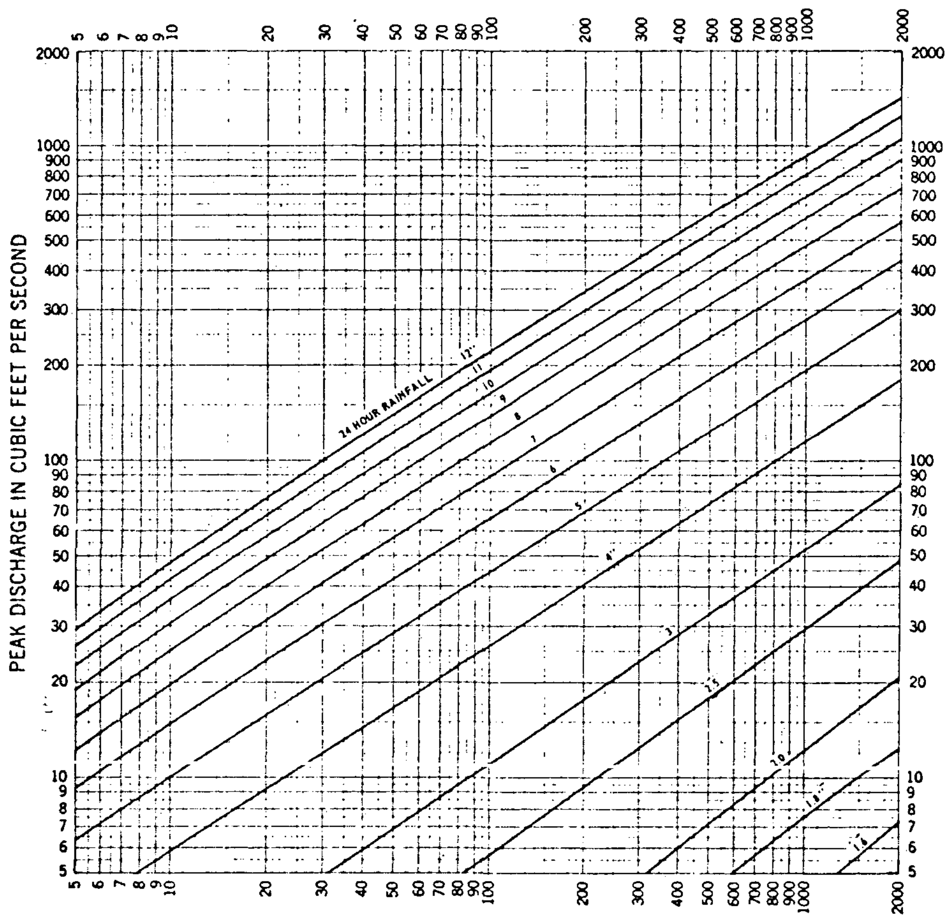


Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		
"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - HYDROLOGY BRANCH	STANDARD DWG. NO. ES-1027 SHEET 2 OF 21 DATE 2-15-71

Figure 3-4. Peak Rates of Discharge for Small Watersheds Type II Storm Distribution.

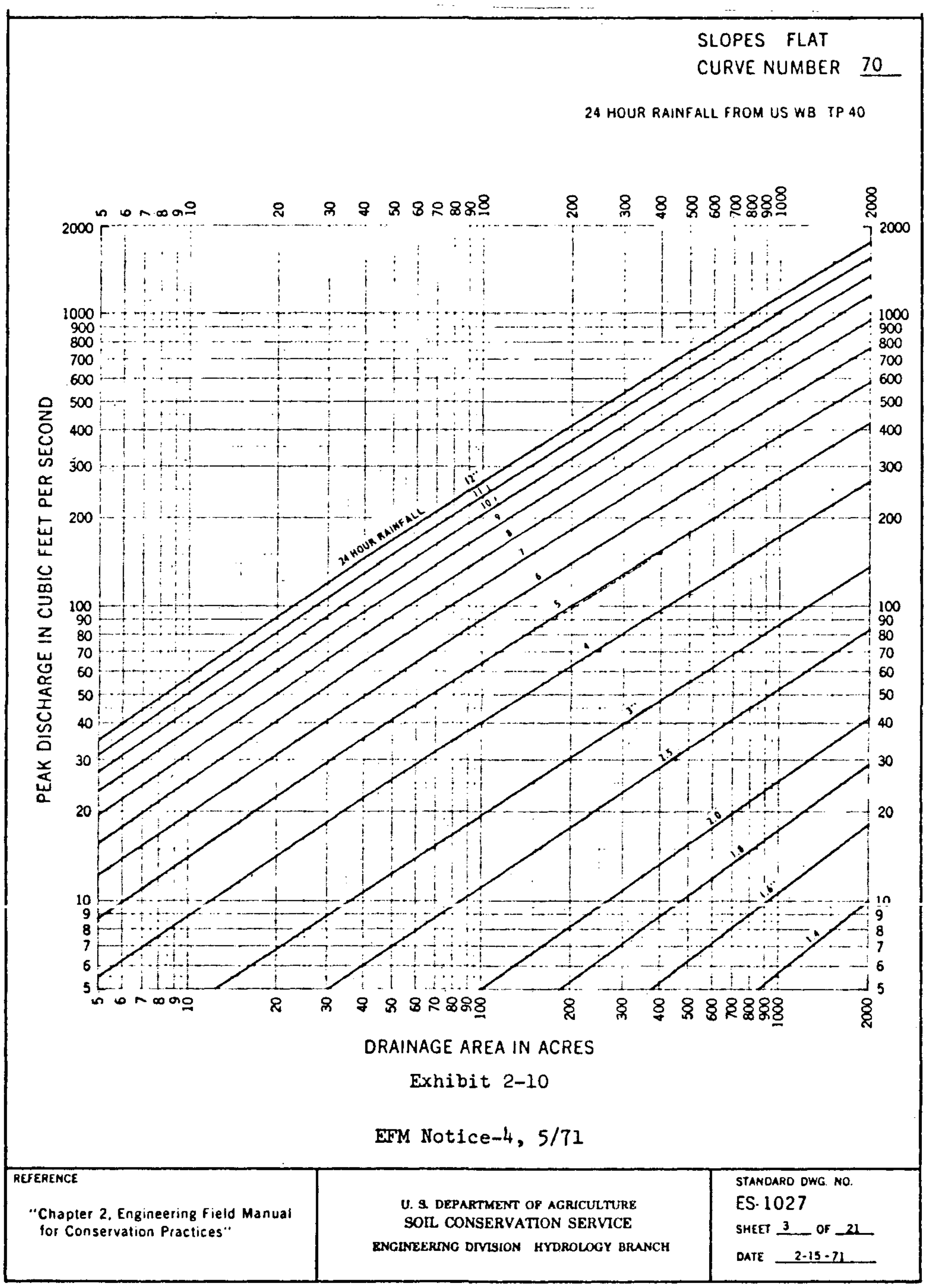
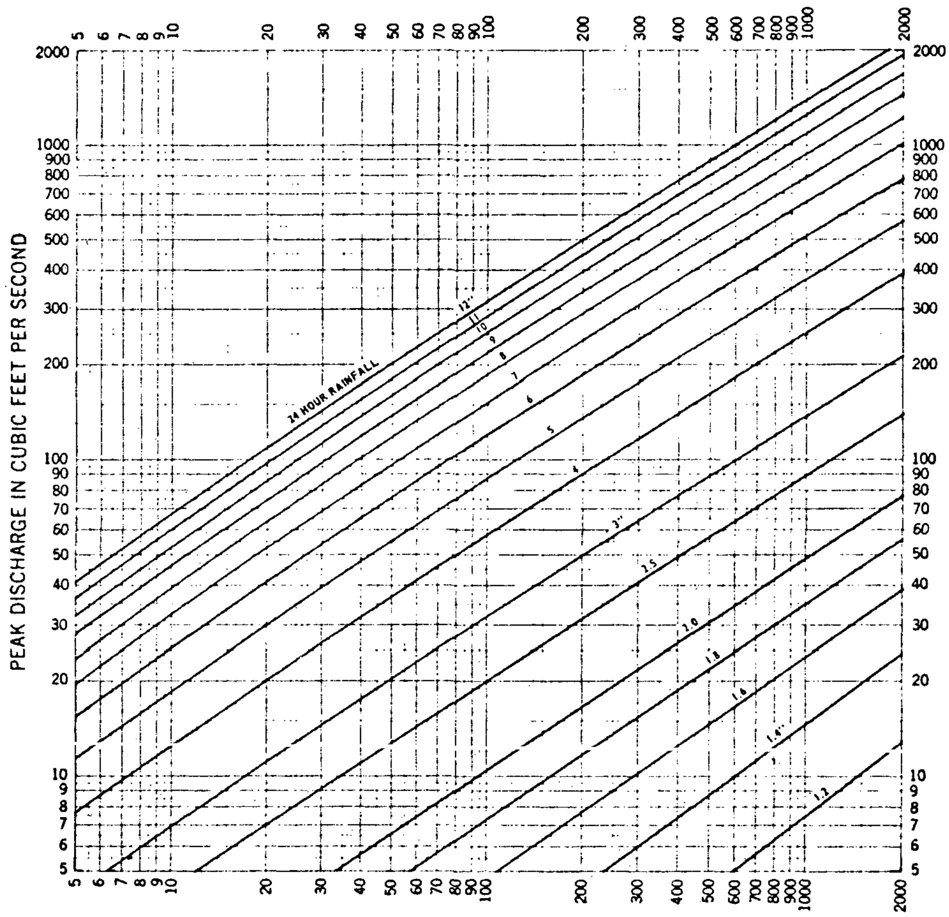


Figure 3-5. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

SLOPES FLAT
CURVE NUMBER 75

24 HOUR RAINFALL FROM US WB TP 40



DRAINAGE AREA IN ACRES

Exhibit 2-10

EFM Notice-4, 5/71

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Figure 3-6. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

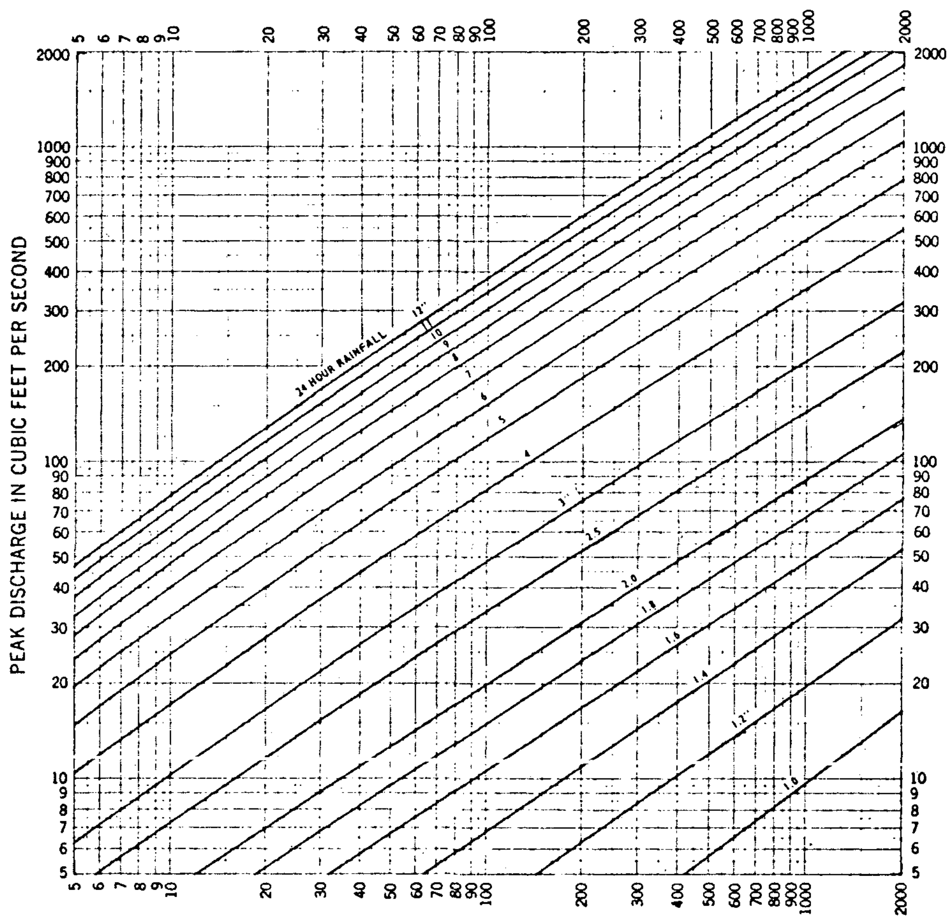

Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		STANDARD DWG. NO.
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Figure 3-7. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

SLOPES - FLAT
CURVE NUMBER 85

24 HOUR RAINFALL FROM US WB TP-40

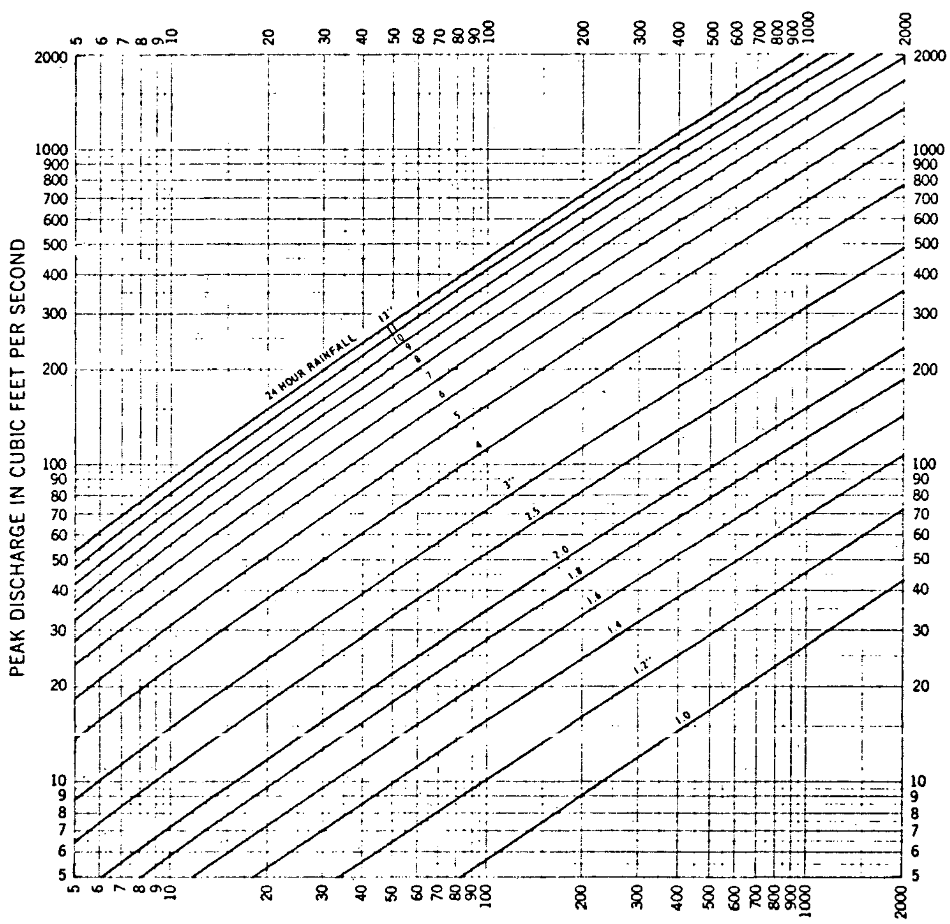

Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		STANDARD DWG. NO.
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Figure 3-8. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

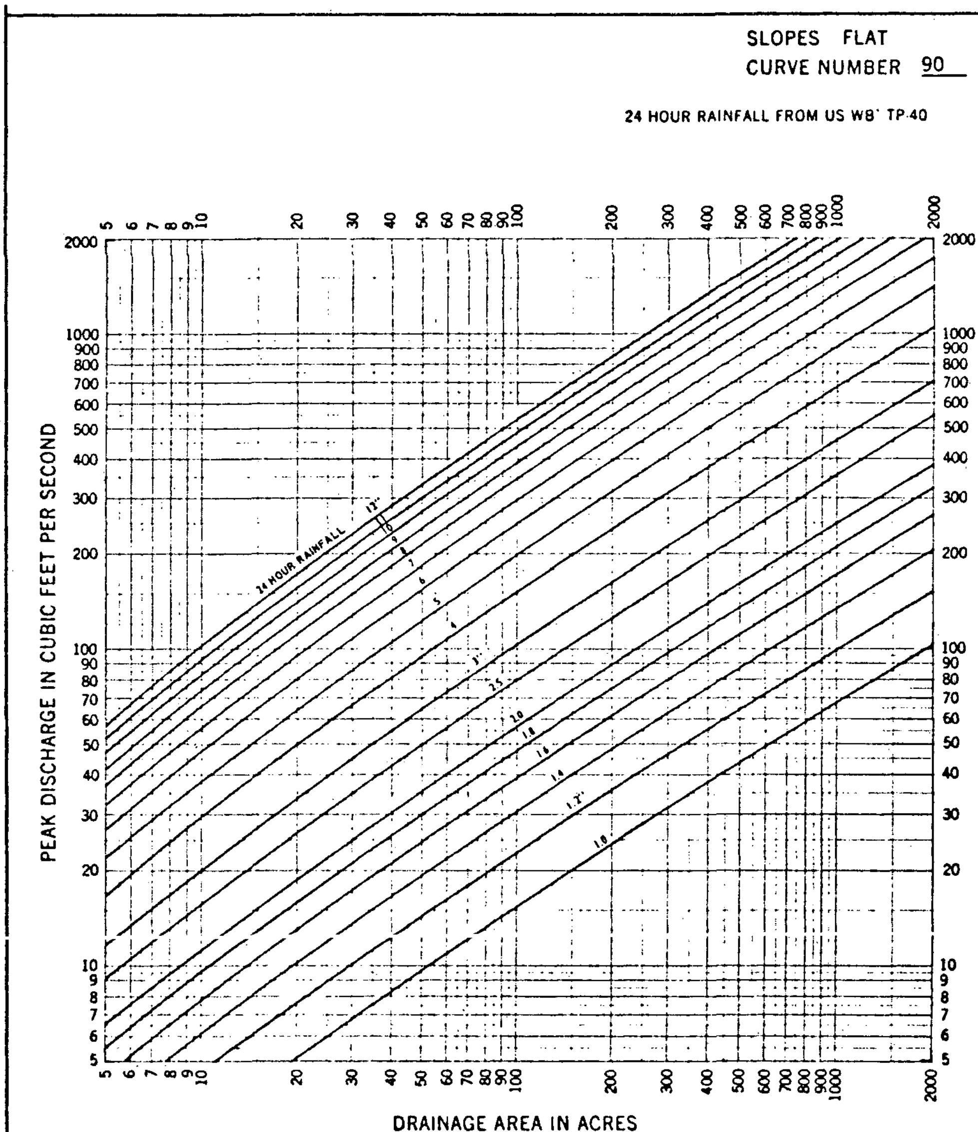

Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		STANDARD DWG. NO.
"Chapter2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION HYDROLOGY BRANCH	ES-1027 SHEET 7 OF 21 DATE 2-15-71

Figure 3-9. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

SLOPES - MODERATE
CURVE NUMBER 60

24 HOUR RAINFALL FROM US WB TP-40

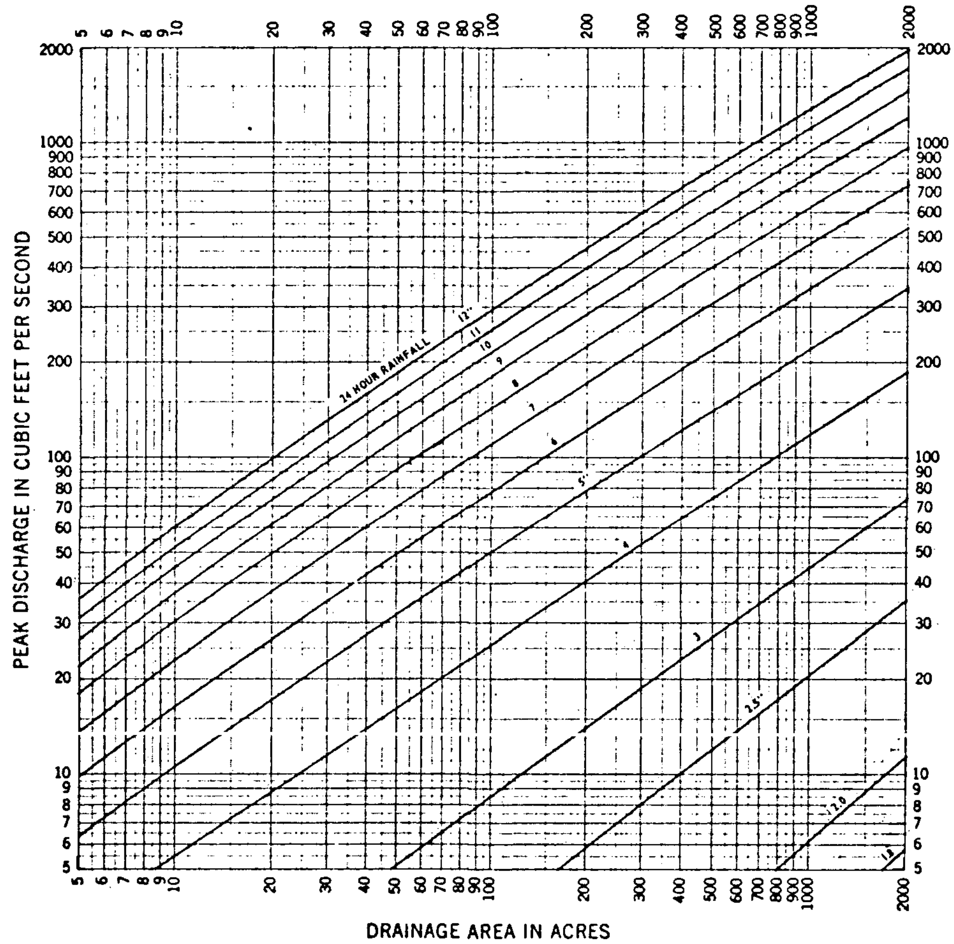

Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		STANDARD DWG. NO.
"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION HYDROLOGY BRANCH	ES-1027 SHEET 8 OF 21 DATE 2-15-71

Figure 3-10. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

SLOPES MODERATE
CURVE NUMBER 65

24 HOUR RAINFALL FROM US WB TP-40

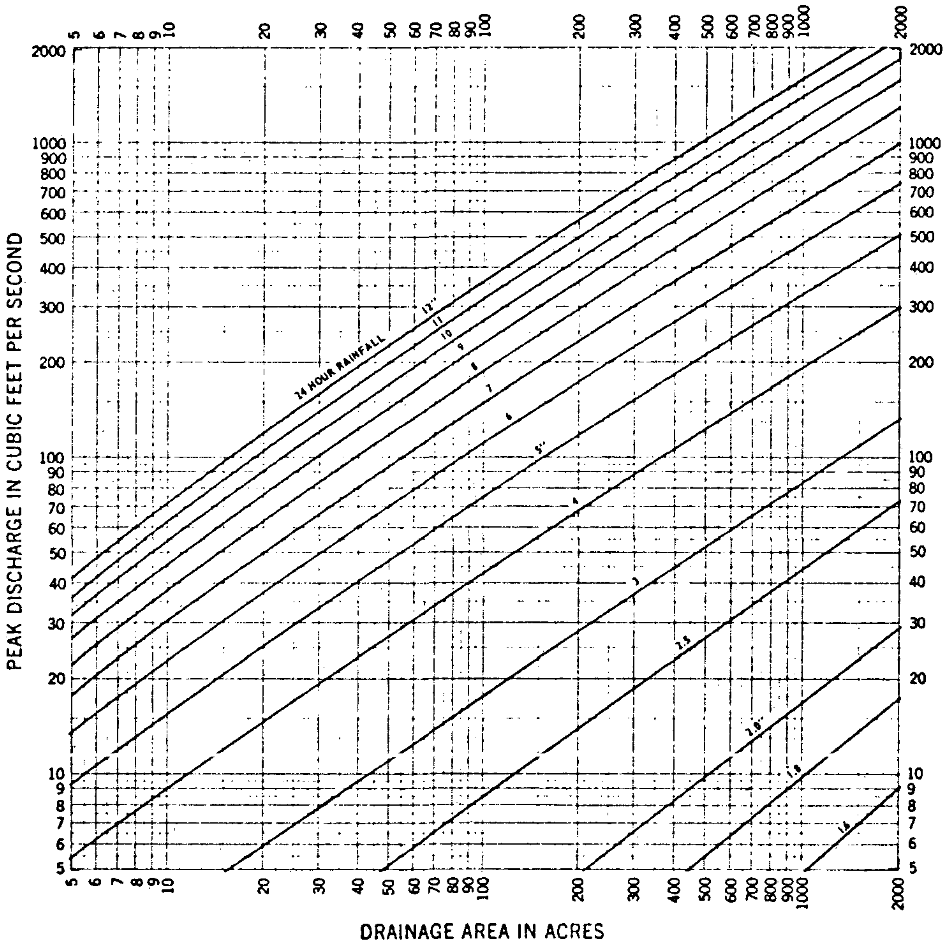

Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		STANDARD DWG. NO.
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Figure 3-11. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

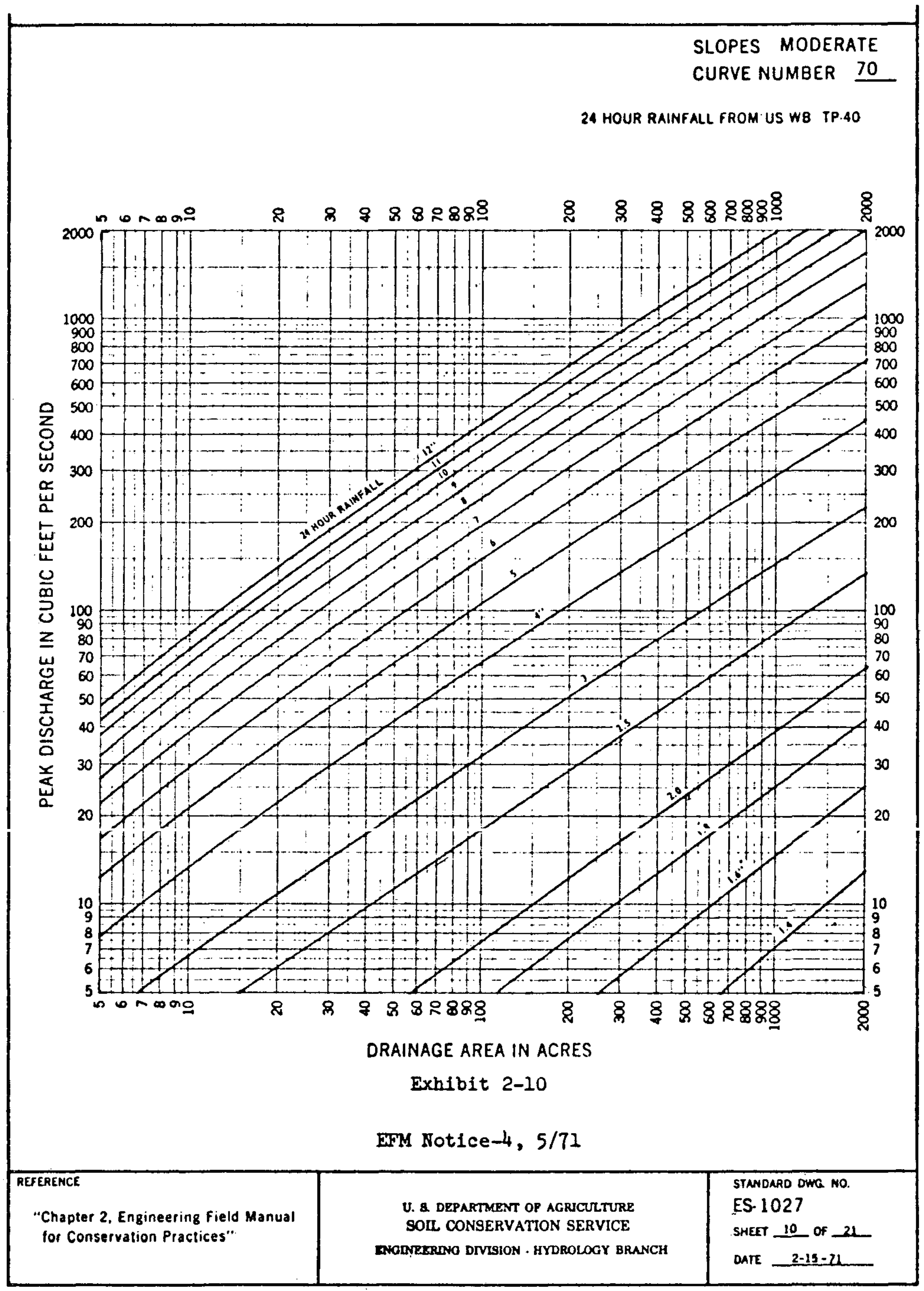

Figure 3-12. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

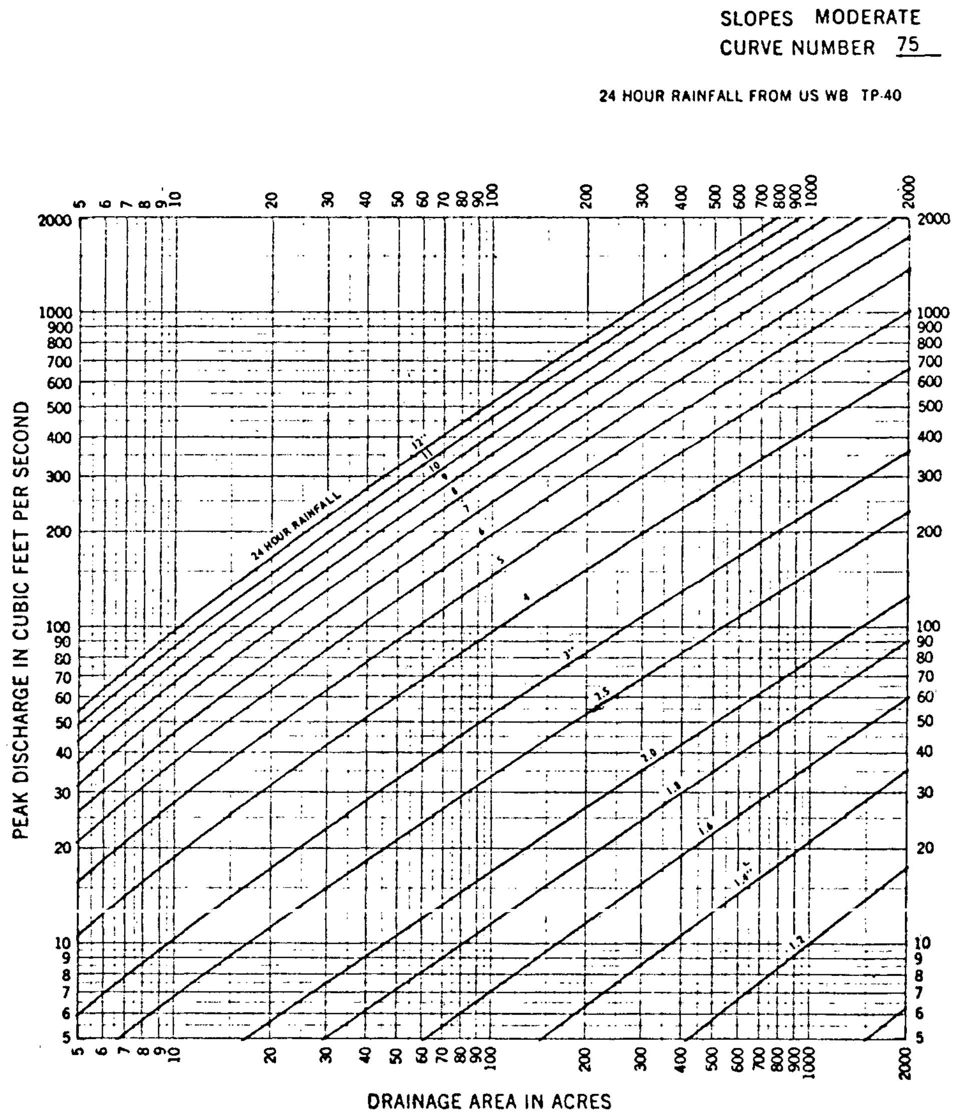

Exhibit 2-10

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"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - HYDROLOGY BRANCH	ES-1027 SHEET 11 OF 21 DATE 2-15-71

Figure 3-13. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

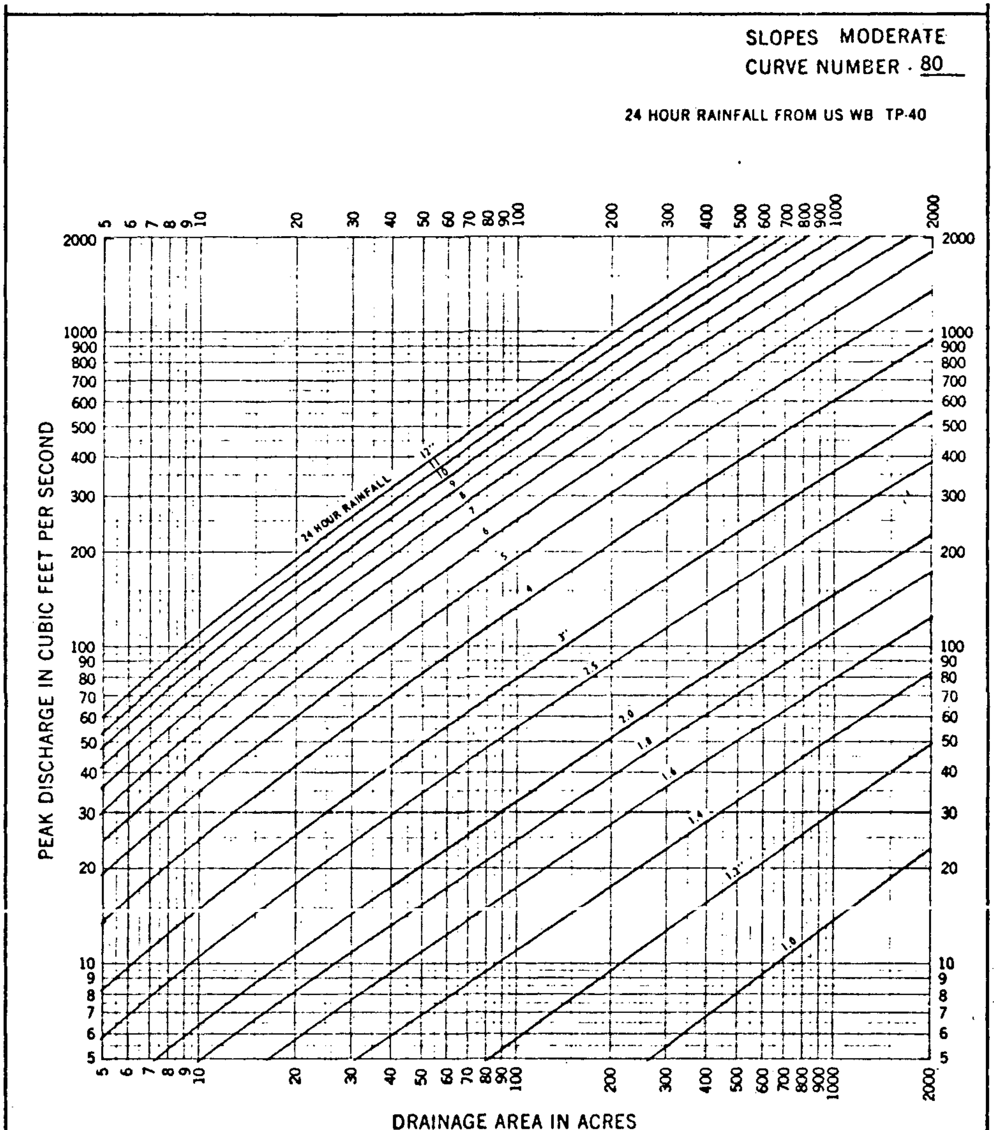


Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		STANDARD DWG. NO.
"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION HYDROLOGY BRANCH	ES-1027 SHEET 12 OF 21 DATE 2-15-71

Figure 3-14. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

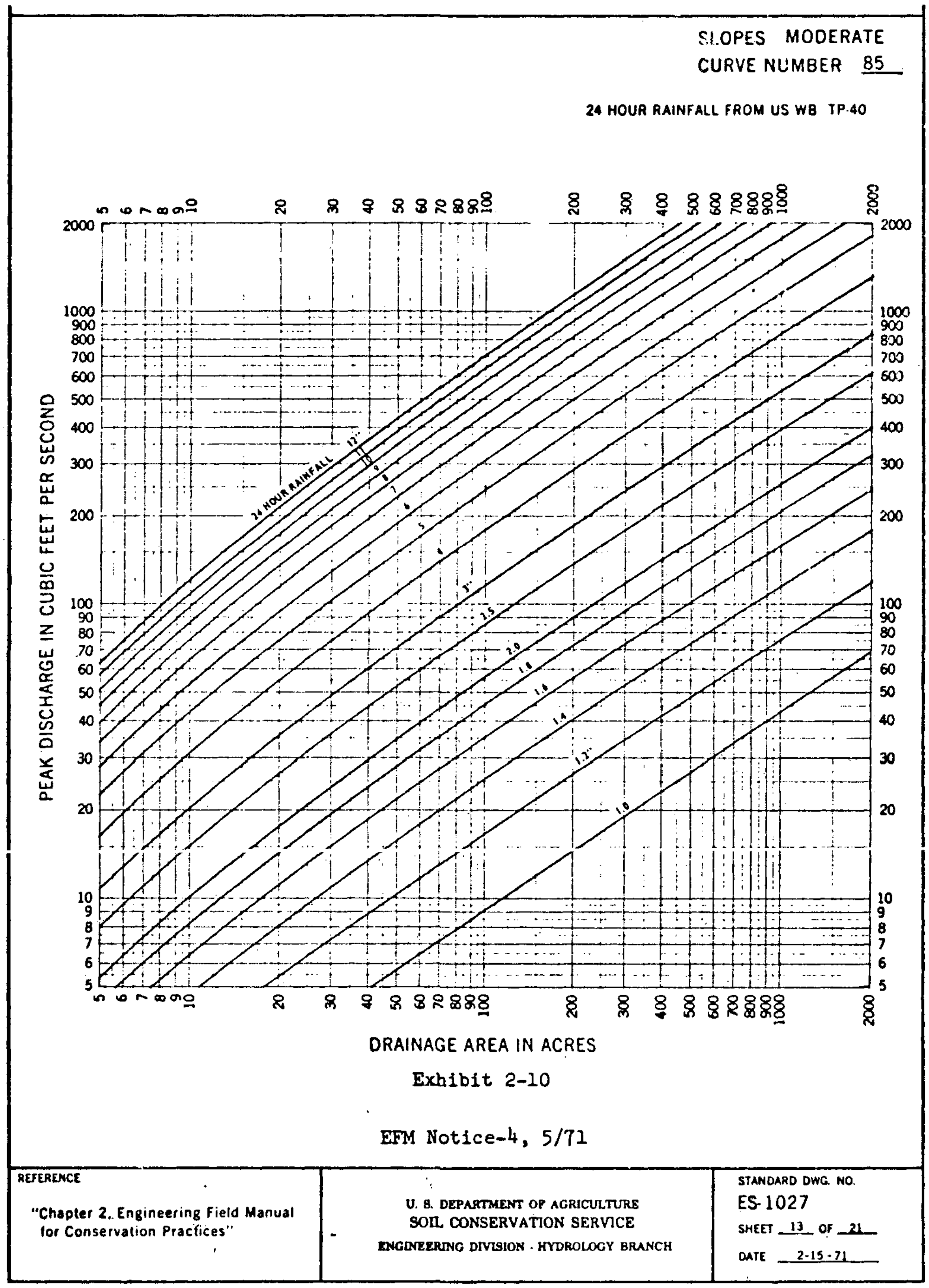


Figure 3-15. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

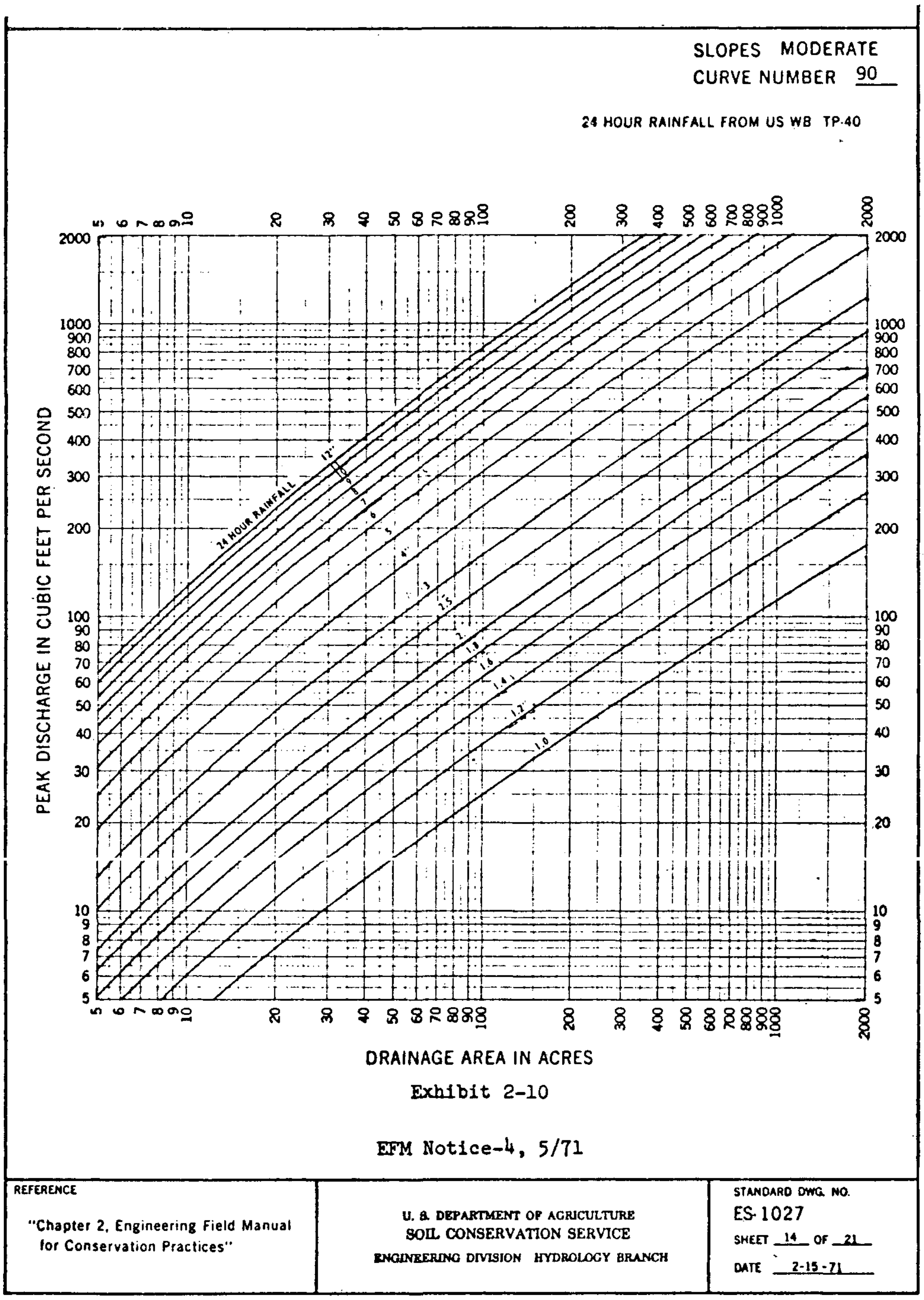


Figure 3-16. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

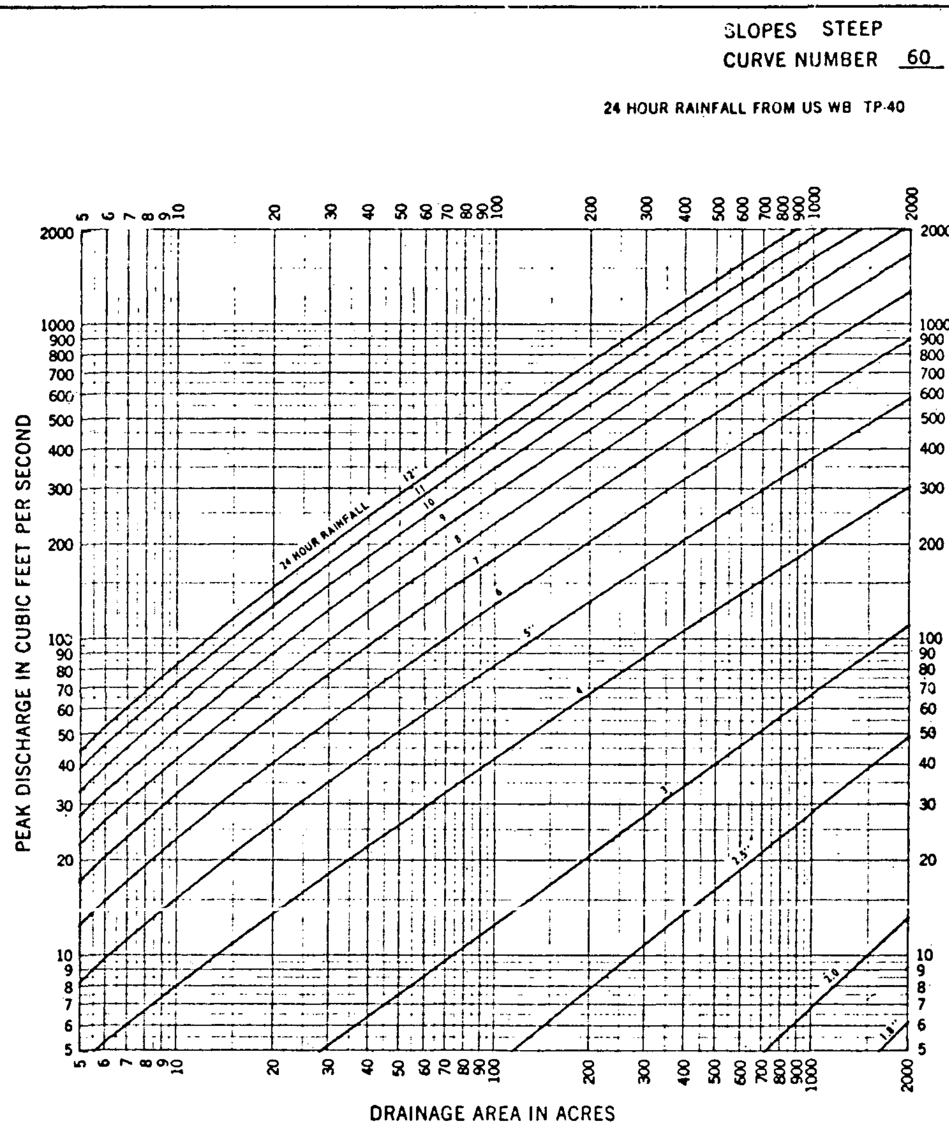


Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		STANDARD DWG. NO.
"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION HYDROLOGY BRANCH	ES-1027 SHEET 15 OF 21 DATE 2-15-71

Figure 3-17. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

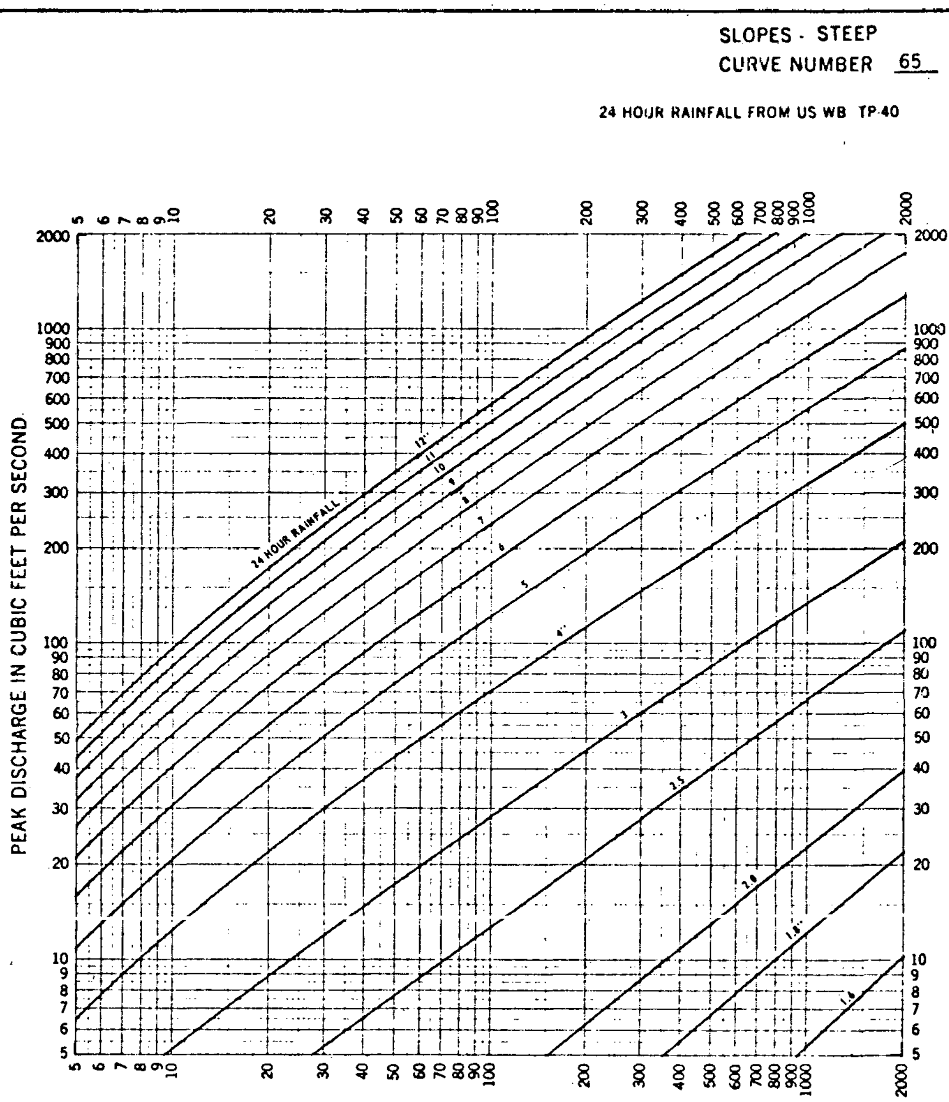


Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		STANDARD DWG. NO.
"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - HYDROLOGY BRANCH	ES-1027 SHEET 16 OF 21 DATE 2-15-71

Figure 3-18. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

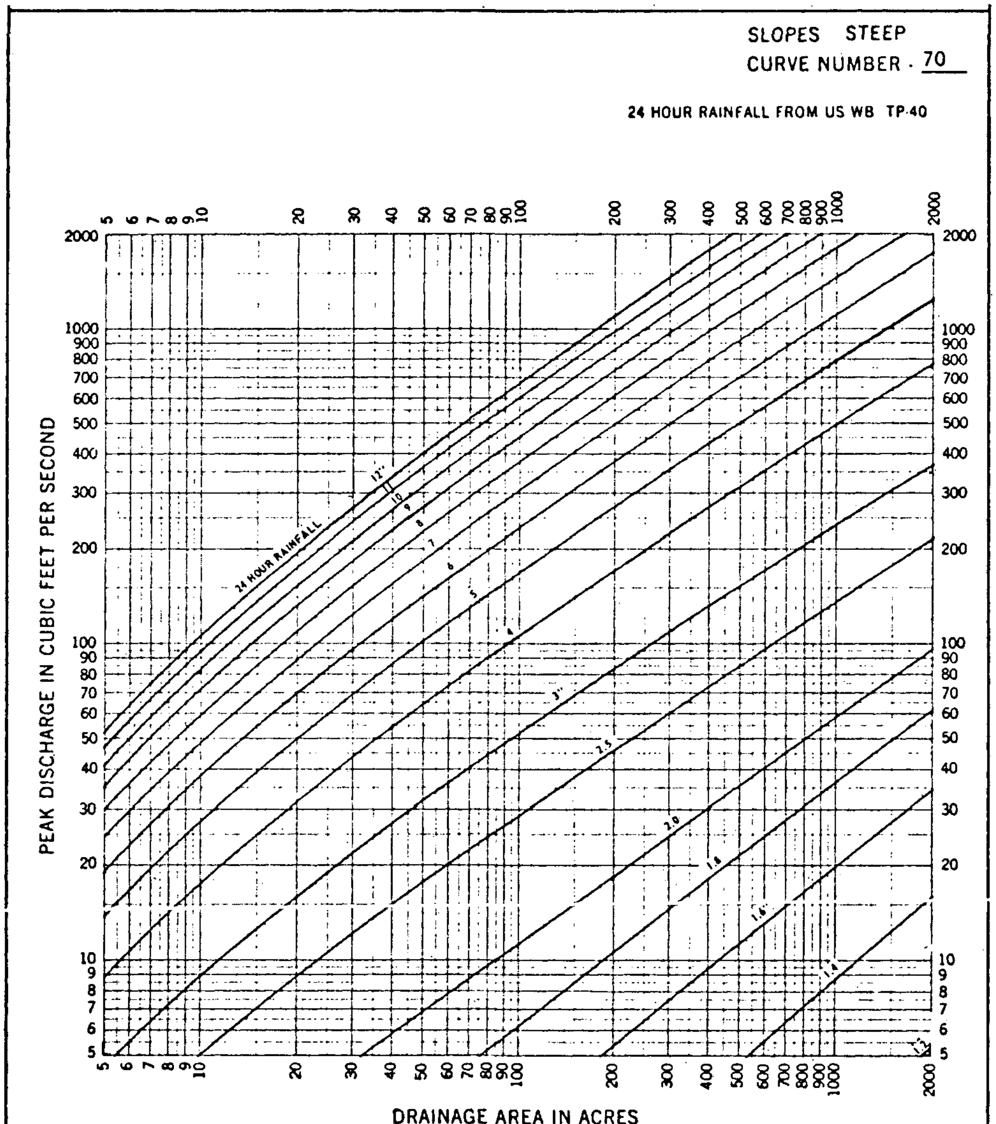


Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		STANDARD DWG. NO.
"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - HYDROLOGY BRANCH	ES-1027 SHEET 17 OF 21 DATE 2-15-71

Figure 3-19. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

SLOPES STEEP
CURVE NUMBER 75

24 HOUR RAINFALL FROM US WB TP-40

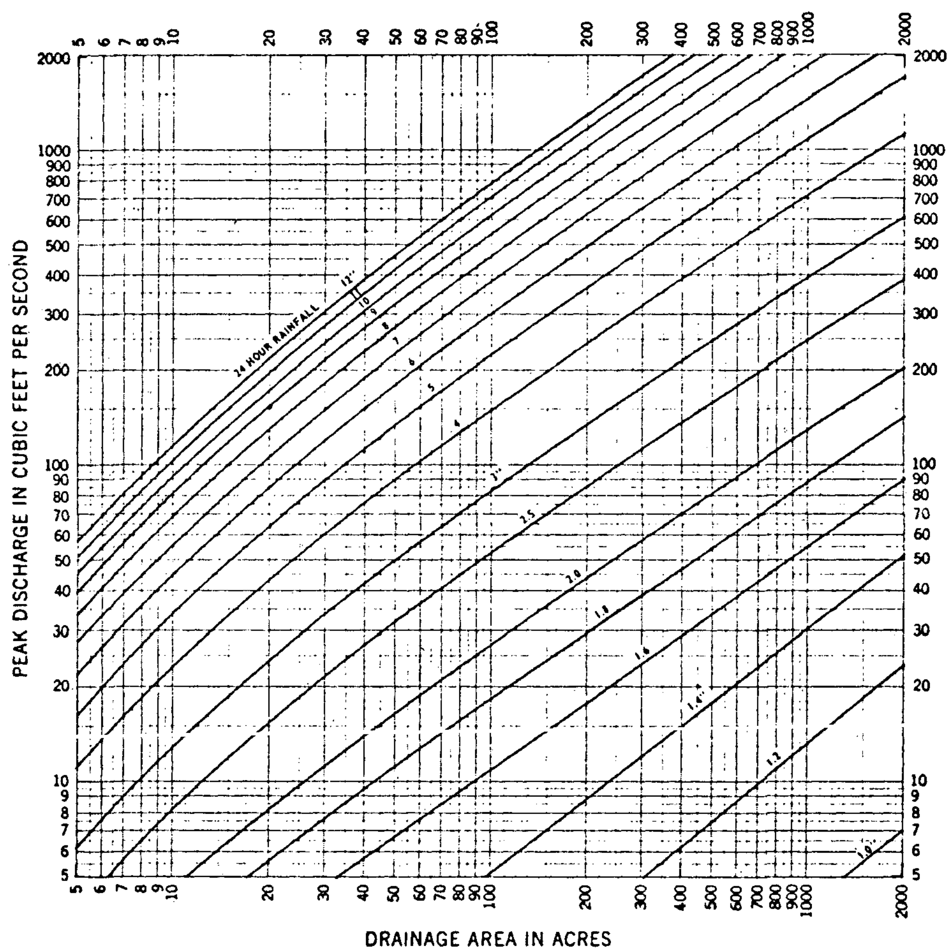


Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		
"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION HYDROLOGY BRANCH	STANDARD DWG. NO. ES-1027 SHEET 18 OF 21 DATE 2-15-71

Figure 3-20. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

SLOPES - STEEP
CURVE NUMBER 80

24 HOUR RAINFALL FROM US WB TP-40

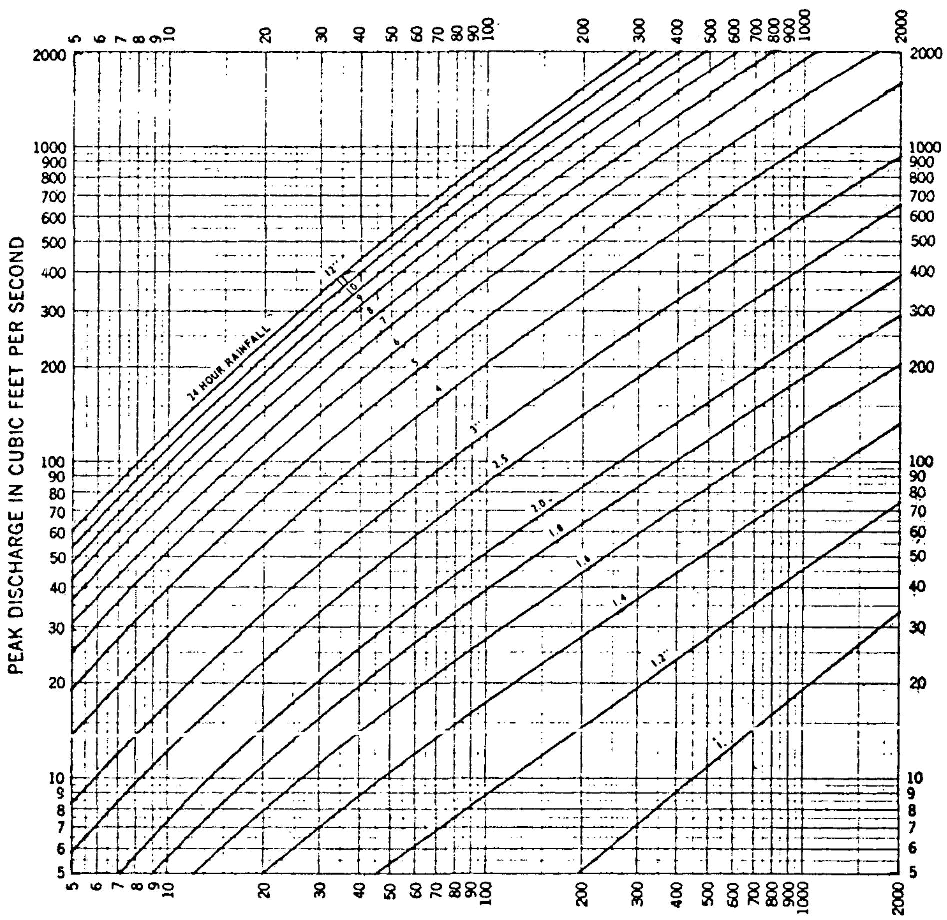


Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		STANDARD DWG. NO.
"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - HYDROLOGY BRANCH	ES-1027 SHEET 19 OF 21 DATE 2-15-71

Figure 3-21. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

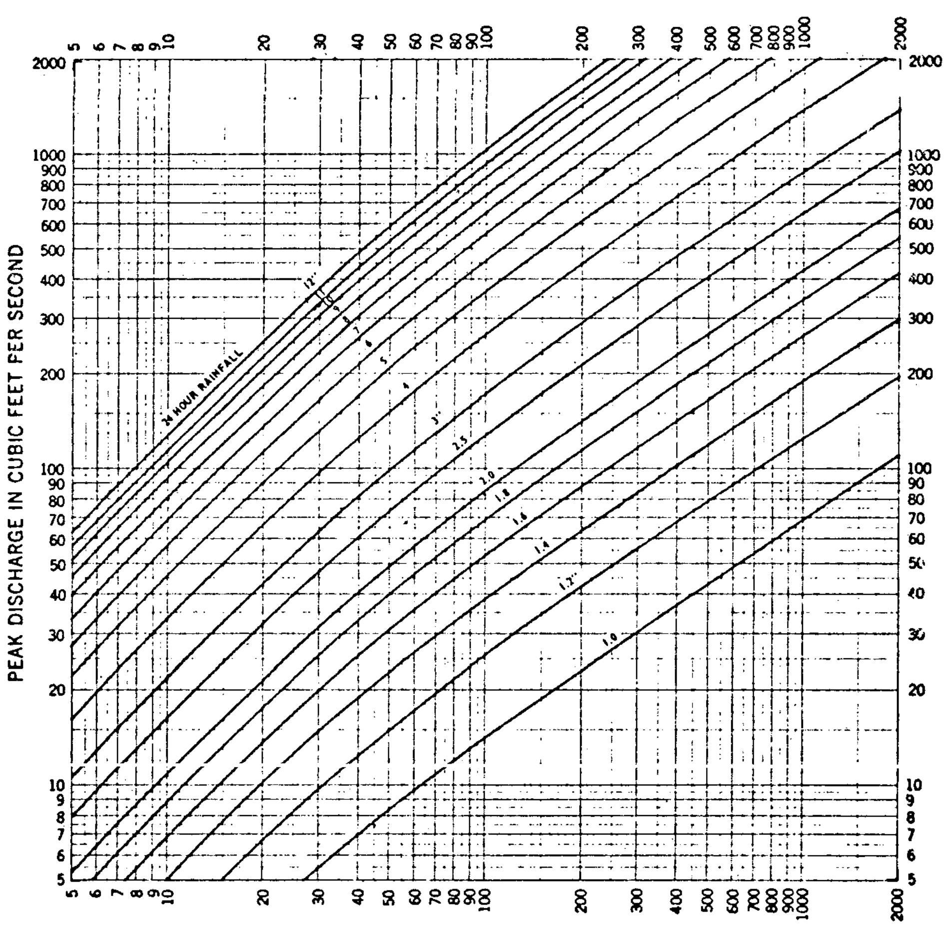


Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		STANDARD DWG. NO.
"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION HYDROLOGY BRANCH	ES-1027 SHEET 20 OF 21 DATE 2-15-71

Figure 3-22. Peak Rates of Discharge for Small Watersheds, Type II Storm Distribution.

SLOPES STEEP
CURVE NUMBER 90

24 HOUR RAINFALL FROM US WB TP 40

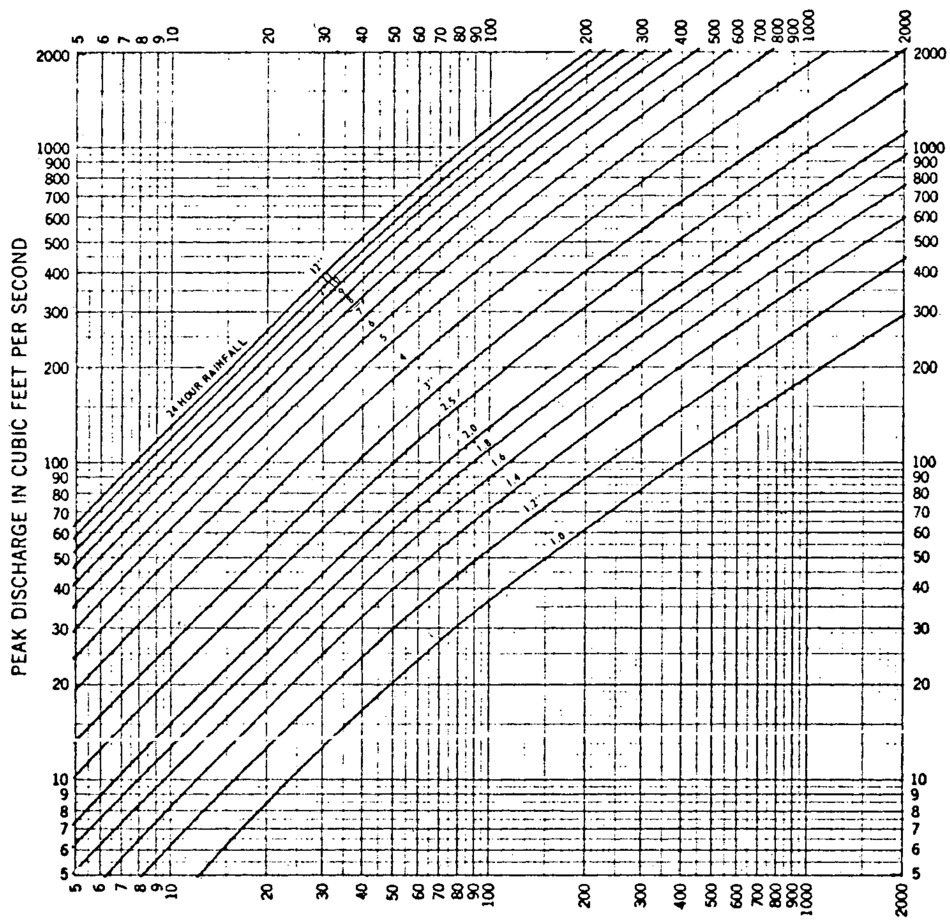


Exhibit 2-10

EFM Notice-4, 5/71

REFERENCE		STANDARD DWG. NO.
"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - HYDROLOGY BRANCH	ES-1027 SHEET 21 OF 21 DATE 2-15-71

Table 3-5. Slope Factors for Peak Discharge Computations.

Slope Factor	Slope Used in Curve Computation	Slope Range Represented
Flat	1	0 to 3
Moderate	4	3 to 8
Steep	16	8 to 30

Example: Determine peak discharge for the following conditions: drainage area--22 acres, slope factor--moderate, runoff curve--No. 70, rainfall amount--5.8 inches. Enter Figure 3-11. Peak discharge is 50 cfs.

Interpolating and Extrapolating

Refinement of the peak rate of discharge determined from the charts may be desired. This can be done by plotting peak rates of discharge for flat, moderate, and steep versus slope values of 1, 4 and 16 percent, respectively. Either interpolations or extrapolations beyond 16 percent may be made. Table 3-5 provides interpolating and extrapolating factors.

Curve Numbers Less Than 60

The peak rate curves do not provide for a runoff curve number less than 60. Table 3-6 provides ratios to apply to the peak runoff rate determined by using CN = 60 in order to get a peak rate corresponding to a lower CN value.

Adjustment for Swamps or Ponding

Ponded areas and swamps have the general effect of reducing runoff below the value determined from the peak runoff curves. As pointed out under the section on "Slope," there are situations where these areas should be excluded from the contributing drainage area because they serve as permanent detention pools. When this is not true, the peak rate from Figures 3-2 to 3-22 can be refined using the adjustment factors of Tables 3-7, 3-8 and 3-9. The choice between tables depends on the location of ponding in the watershed. The peak rate from the peak rate curves is multiplied by the appropriate factor from the table to determine the adjusted peak runoff rate.

Table 3-6. Interpolating or Extrapolating Peak Discharge for Average Watershed Slopes from .1% to 75%.

INTERPOLATING FACTORS FOR VARIOUS SLOPES AND DRAINAGE AREAS

Flat Slopes--round to nearest % slope shown
(Use discharge values from ES sheets labeled "Flat")

Slope %	Acres 1-50	Acres 51-500	Acres 501-2000
.1	.47	.43	.40
.2	.58	.55	.53
.3	.66	.64	.62
.4	.74	.71	.70
.5	.79	.77	.76
.7	.89	.88	.87
1.0	1.00	1.00	1.00
2.0	1.13	1.16	1.18

Moderate Slopes--round to nearest % slope shown
(Use discharge values from ES sheets labeled "Moderate")

Slope %	Acres 1-50	Acres 51-500	Acres 501-2000
3	.96	.95	.94
4	1.00	1.00	1.00
5	1.04	1.05	1.06
6	1.07	1.10	1.11
7	1.09	1.13	1.15

Steep Slopes--round to nearest % slope shown
(Use discharge values from ES sheets labeled "Steep")

Slope %	Acres 1-50	Acres 51-500	Acres 501-2000
8	.92	.88	.83
9	.93	.90	.85
10	.94	.91	.87
11	.95	.93	.89
12	.96	.94	.91
13	.97	.96	.94
14	.98	.97	.96
15	.99	.99	.98
16	1.00	1.00	1.00
17	1.01	1.02	1.02
18	1.02	1.03	1.04
19	1.03	1.05	1.06

Steep Slopes (continued)

Slope %	Acres 1-50	Acres 51-500	Acres 501-2000
20	1.04	1.08	1.08
25	1.08	1.14	1.17
30	1.11	1.20	1.23
35	1.13	1.24	1.28
40	1.16	1.29	1.33
45	1.18	1.31	1.37
50	1.21	1.34	1.40
55	1.23	1.35	1.43
60	1.26	1.37	1.46
65	1.28	1.39	1.48
70	1.30	1.40	1.50
75	1.32	1.42	1.52

Table 3-6 (Continued).

Example:

Given

1.	D.A.	=	1000 acres
2.	Rainfall	=	4 Inches
3.	C.N.	=	80
4.	Slope	=	41%

Determine

Peak flow

Solution

1. 41% slope is in the steep category.
   From ES 1027 - slopes, steep;
   CN 80 - peak discharge
   = 1000 cfs.

2. From table for steep slopes and under 501-2000 acres drainage area and on line with 40% slope (41 rounded to 40) find factor 1.33.

3. Peak flow = 1000 x 1.33 = 1330 cfs.

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 2.8.

Table 3-7. Factors for Adjusting CN = 60 Peak Discharge Rates to Reflect Runoff Curve Numbers <60.

Runoff Curve No.	24-HOUR RAINFALL (Inches) 12	11	10	9	8	7	6	5	4
60	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
55	.88	.87	.86	.85	.83	.81	.79	.75	.70
50	.76	.74	.73	.70	.67	.64	.59	.53	.43
45	.64	.61	.59	.56	.52	.48	.42	.34	.24
40	.51	.49	.46	.42	.37	.32	.26	.18	.08

Example: A = 100 acres Type II Storm
Slope: flat
24 hour rainfall = 6.0"
CN = 50

From Figure 3-2, q = 46 cfs for CN = 60

Then: For CN = 50
q = 46 × 0.59 = 27 cfs
(Ratio of 0.59 obtained from table where rainfall = 6.0" and runoff curve number = 50)

Source: U.S. Department of Agriculture, Soil Conservation Service, Alabama Engineering Field Manual for Conservation Practices, (1972), Auburn, Alabama, p. 2-36.

Table 3-8. Adjustment Factors Where Ponding and Swampy Areas Occur at Design Point.

Ratio	Percent	Frequency					
D.A./Pond and Swampy Area	Pond and Swamp in D.A.	2	5	10	25	50	100
500	0.2	.92	.94	.95	.96	.97	.98
200	0.5	.86	.87	.88	.90	.92	.93
100	1.0	.80	.81	.83	.85	.87	.89
50	2.0	.74	.75	.76	.79	.82	.86
40	2.5	.69	.70	.72	.75	.78	.82
30	3.3	.64	.65	.67	.71	.75	.78
20	5.0	.59	.61	.63	.67	.71	.75
15	6.7	.57	.58	.60	.64	.67	.71
10	10.0	.53	.54	.56	.60	.63	.68
5	20.0	.48	.49	51	55	59	.64

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices, (1969), pp. 2-82.3 to 2-82.4.

Table 3-9. Adjustment Factors Where Ponding and Swampy Areas are Spread Throughout Watershed or Occur in Central Parts of Watershed.

Ratio	Percent	Frequency					
D.A./Pond and Swampy Area	Pond and Swamp in D.A.	2	5	10	25	50	100
500	0.2	.94	.95	.96	.97	.98	.99
200	0.5	.88	.89	.90	.91	.92	.94
100	1.0	.83	.84	.86	.87	.88	.90
50	2.0	.78	.79	.81	.83	.85	.87
40	2.5	.73	.74	.76	.78	.81	.84
30	3.3	.69	.70	.71	.74	.77	.81
20	5.0	.65	.66	.68	.72	.75	.78
15	6.7	.62	.63	.65	.69	.72	.75
10	10.0	.58	.59	.61	.65	.68	.71
5	20.0	.53	.54	.56	.60	.63	.68
4	25.0	.50	.51	.53	.57	.61	.66
3	33.3	.47	.49	.50	.54	.59	.64
2	50.0	.45	.47	.48	.52	.57	.62
1	100.0	.43	.45	.46	.50	.55	.61

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual For Conservation Practices, (1969), pp. 2-82.3--2-82.4.

Table 3-10. Adjustment Factors Where Ponding and Swampy Areas are Located in Upper Reaches of Watershed.

Ratio	Percent	Frequency					
D.A./Pond and Swampy Area	Pond and Swamp in D.A.	2	5	10	25	50	100
500	0.2	.96	.97	.98	.98	.99	.99
200	0.5	.93	.94	.94	.95	.96	.97
100	1.0	.90	.91	.92	.93	.94	.95
50	2.0	.87	.88	.88	.90	.91	.93
40	2.5	.85	.85	.86	.88	.89	.91
30	3.3	.82	.83	.84	.86	.88	.89
20	5.0	.80	.81	.82	.84	.86	.88
15	6.7	.78	.79	.80	.82	.84	.86
10	10.0	.77	.77	.78	.80	.82	.84
5	20.0	.74	.75	.76	.78	.80	.82

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices, (1969), pp. 2-82.3--2-82.4.

LITERATURE CITED

1. U.S. Department of Agriculture, Soil Conservation Service, A Method For Estimating Volume and Rate of Runoff in Small Watersheds, SCS-TP-149 (1968).

2. U.S. Department of Agriculture, Soil Conservation Service, National Engineering Handbook, Section 4--Hydrology, 1972.

CHAPTER IV

STABILIZATION DESIGN

The logical solution to a gully problem is to provide a measure that solves the problem with the least annual cost and still provides an aesthetically pleasing solution. To be very honest, though, it is not always possible or practical to give much weight to aesthetics. All solutions tend to improve aesthetics, but some are not very pretty.

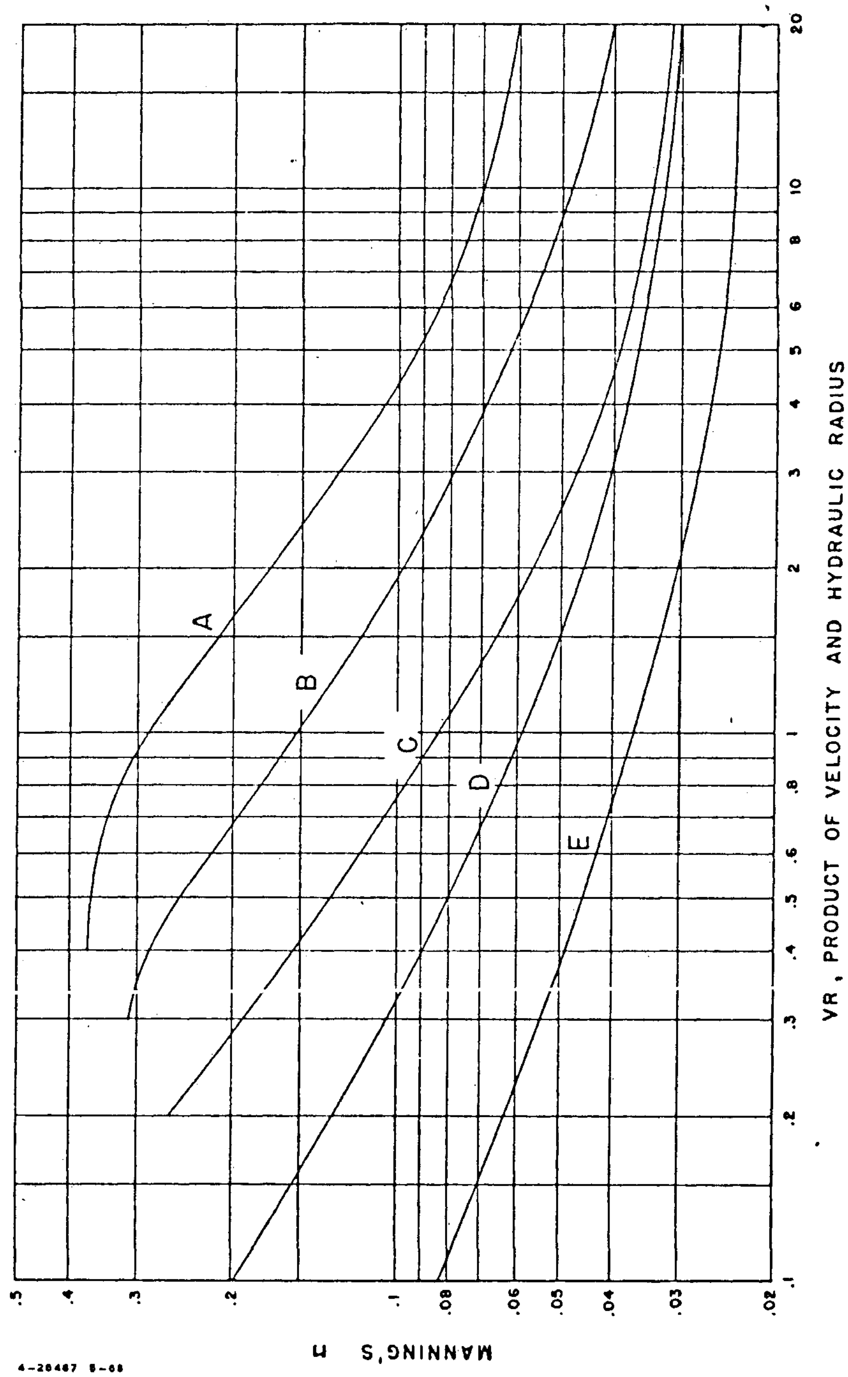
Since economics always is foremost in the mind of whoever must pay for the measures, it is important to first look at the possibility of a vegetative solution. Pure vegetative solutions are pretty well limited to non-overfall (non-headcutting) gullies and to gullies that have worked their way to a watershed divide. The next degree of treatment involves earthwork plus vegetative work. This may involve shaping and filling to form a waterway, a diversion, or possibly both. Finally, there are structural solutions, which always rely heavily on vegetation. Structures may be employed both to stop a headcut and to limit gradient within a gully.

Waterways

A waterway must be designed and built in such a way that it will not erode. This limits its applicability. Waterways are usually designed to accomodate runoff from a 10-year, 24-hour storm without developing erosive velocities when fully vegetated. The velocity actually experienced in a particular waterway depends primarily upon the type of vegetation in the waterway, plant height, and plant density. These conditions in turn are dependent on the season and the care the waterway receives. Vegetal conditions control flow retardance--the retarding coefficient "n" in Manning's formula. It has been shown that retardance for a particular plant cover varies according to VR, the product of velocity and hydraulic radius. The variation results from the tendency of plants to bend and "give" with flow in varying degrees, depending primarily on depth and velocity of flow (1, p. 7-5). Figure 4-1 categorizes variation of retardance according to five curves labeled A, B, C, D and E. Table 4-1 shows the degree of retardance created by various plants at different plant heights.

Table 4-2 gives permissible design velocities for waterways lined with vegetation. They represent the long-term operating velocities that can be tolerated in the waterway--if vegetation is successfully established. In order to select adequate waterway

Figure 4-1. Manning's "n" related to velocity, hydraulic radius, and vegetal retardance.



Source: U.S. Department of Agriculture, Soil Conservation Service, <u>Handbook of Channel Design for Soil and Water Conservation,</u> by Stillwater Outdoor Hydraulic Laboratory, SCS-TP-61, (Revised June, 1954), p. 25.

Table 4-1. Classification of Vegetation Cover as to Degree of Retardance.

Retardance	Cover	Condition
A	Reed canarygrass	Excellent stand, tall (average 36 inches)
	Yellow bluestem Ischaemum	Excellent stand, tall (average 36 inches)
B	Smooth bromegrass	Good stand, mowed (average 12 to 15 inches)
	Bermudagrass	Good stand, tall (average 12 inches)
	Native grass mixture (little bluestem, blue grama, and other long and short midwest grasses)	Good stand, unmowed
	Tall fescue	Good stand, unmowed (average 18 inches)
	Lespedeza sericea	Good stand, not woody, tall (average 19 inches)
	Grass-legume mixture--Timothy, smooth bromegrass, or orchard grass	Good stand, uncut (average 20 inches)
	Reed canarygrass	Good stand, mowed (average 12 to 15 inches)
	Tall fescue, with bird's foot trefoil or lodino ..	Good stand, uncut (average 18 inches)
	Blue grama	Good stand, uncut (average 13 inches)
C	Bahia	Good stand, uncut (6 to 8 inches)
	Bermudagrass	Good stand, mowed (average 6 inches)
	Redtop	Good stand, headed (15 to 20 inches)
	Grass-legume mixture--summer (Orchard grass, redtop, Italian ryegrass, and common lespedeza) ...	Good stand, uncut (6 to 8 inches)
	Centipedegrass	Very dense cover (average 6 inches)
	Kentucky bluegrass	Good stand, headed (6 to 12 inches)
D	Bermudagrass	Good stand, cut to 2.5-inch height
	Red fescue	Good stand, headed (12 to 18 inches)
	Buffalograss	Good stand, uncut (3 to 6 inches)
	Grass-legume mixture--fall, spring (Orchard grass, redtop, Italian ryegrass, and common lespedeza).	Good stand, uncut (4 to 5 inches)
	Lespedeza sericea	After cutting to 2-inch height. Very good stand before cutting
E	Bermudagrass	Good stand, cut to 1.5-inch height.
	Bermudagrass	Burned stubble.

Source: U.S. Department of Agriculture, Soil Conservation Service, Handbook of Channel Design for Soil and Water Conservation, by Stillwater Outdoor Hydraulic Laboratory, revised June, 1954. SCS-TP-61, p. 11.

Table 4-2. Permissible Velocities for Channels Lined With Vegetation.

Cover	Slope Range (percent)[1]	Permissible Velocity: Erosion Resistant Soils (ft. per second)	Permissible Velocity: Easily Eroded Soils (ft. per second)
Bermudagrass Bahia Tall Fescue	0-10	4.0	3.0
Lespedeza sericea Weeping lovegrass Red fescue	0-5	3.5	2.5
Common lespedeza	0-5	3.5	2.5

[1]Do not use on slopes steeper than 10 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.

Source: U.S. Department of Agriculture, Soil Conservation Service, Alabama Engineering Field Design Manual for Conservation Practices, Auburn, Alabama (1972), p. 7-2.

size, enter Table 4-3 with the appropriate permissible velocity, which appears as V_1 on the table, and the peak runoff rate from the 10-year, 24-hour storm, which is Q on the table. If, for example, $V_1 = 2.0$ fps and Q = 60 cfs, a waterway with a 5 percent gradient would have to be 114.2 feet wide and only 0.57 deep to safely handle the 10-year design storm (Table 4-3, Page 127).

Table 4-3. Parabolic Waterway Design (Retardance "D" and "C").

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 0.25 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15																											
20																											
25	9.6	2.36	1.63																								
30	11.4	2.31	1.68																								
35	13.2	2.27	1.73																								
40	15.0	2.25	1.76	10.4	2.67	2.13																					
45	16.8	2.23	1.78	11.6	2.62	2.19																					
50	18.6	2.21	1.80	12.8	2.59	2.24																					
55	20.4	2.20	1.82	14.0	2.56	2.28																					
60	22.2	2.19	1.83	15.2	2.53	2.31																					
65	24.0	2.18	1.84	16.5	2.54	2.30																					
70	25.8	2.18	1.85	17.7	2.52	2.33	12.6	3.05	2.70																		
75	27.6	2.17	1.86	18.9	2.51	2.35	13.4	3.00	2.76																		
80	29.4	2.17	1.87	20.1	2.50	2.37	14.3	3.01	2.76																		
90	33.1	2.17	1.86	22.6	2.49	2.38	16.0	2.97	2.81																		
100	36.7	2.17	1.87	25.1	2.49	2.38	17.7	2.95	2.85																		
110	40.3	2.16	1.88	27.5	2.47	2.41	19.4	2.93	2.88																		
120	43.9	2.16	1.89	30.0	2.47	2.41	21.1	2.91	2.91	15.2	3.58	3.28															
130	47.6	2.16	1.88	32.5	2.48	2.41	22.8	2.89	2.93	16.4	3.55	3.32															
140	51.2	2.16	1.88	34.9	2.46	2.43	24.6	2.91	2.91	17.6	3.53	3.35															
150	54.8	2.16	1.89	37.4	2.47	2.42	26.3	2.90	2.93	18.8	3.51	3.39															
160	58.4	2.16	1.89	39.9	2.47	2.42	28.0	2.89	2.95	20.0	3.49	3.41															
170	62.0	2.16	1.89	42.3	2.46	2.43	29.7	2.88	2.96	21.2	3.47	3.44	16.7	4.03	3.75												
180	65.6	2.16	1.90	44.8	2.47	2.43	31.4	2.87	2.97	22.4	3.46	3.46	17.6	4.00	3.81												
190	69.2	2.16	1.90	47.2	2.46	2.44	33.1	2.87	2.98	23.6	3.45	3.48	18.5	3.97	3.85												
200	72.8	2.16	1.90	49.7	2.46	2.44	34.9	2.88	2.97	24.8	3.44	3.49	19.4	3.94	3.90												
220	80.0	2.16	1.90	54.6	2.46	2.44	38.3	2.87	2.99	27.2	3.42	3.53	21.3	3.92	3.92												
240	87.3	2.16	1.90	59.5	2.46	2.45	41.7	2.86	3.00	29.6	3.40	3.55	23.1	3.88	3.99												
260	94.5	2.16	1.90	64.5	2.46	2.44	45.2	2.86	3.00	32.1	3.41	3.54	25.0	3.87	4.01	19.5	4.57	4.34									
280	101.7	2.16	1.90	69.4	2.46	2.45	48.6	2.85	3.01	34.5	3.40	3.56	26.9	3.86	4.02	21.0	4.57	4.34									
300	108.9	2.16	1.90	74.3	2.46	2.45	52.1	2.86	3.00	36.9	3.39	3.58	28.7	3.83	4.07	22.4	4.53	4.40									

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), pp. 7-29 to 7-42.

Table 4-3 (Continued).

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 0.50 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	8.6	1.63	1.58												
20	11.3	1.58	1.66												
25	14.1	1.57	1.67	9.0	1.91	2.14									
30	16.9	1.56	1 68	10.7	1.87	2.21	8.2	2 18	2.48						
35	19.6	1.55	1.71	12.4	1.85	2.26	9.4	2.10	2.62						
40	22.4	1.55	1.71	14.1	1.83	2.30	10.7	2.08	2.66						
45	25.1	1.54	1.73	15.8	1.82	2 33	11.9	2.03	2 76						
50	27.9	1.54	1.73	17.5	1.80	2.35	13.2	2.02	2.78	9.6	2.42	3.19			
55	30.7	1.54	1 72	19 2	1.80	2 37	14.5	2.02	2.79	10.5	2.39	3.25			
60	33.4	1.54	1.74	20.9	1 79	2 38	15.8	2.01	2.80	11.4	2.37	3.30			
65	36.1	1.53	1.75	22.7	1.80	2.36	17.0	1.99	2 86	12.3	2.35	3.34			
70	38 9	1 54	1 74	24.4	1.80	2.37	18.3	1.99	2.86	13.2	2.33	3.38			
75	41.6	1.54	1.75	26.1	[illegible]	2.38	19.6	1.99	2.86	14.1	2.32	3.41	11.2	2.71	3.66
80	44.3	1.53	1.75	27.8	1.79	2.39	20.9	1.99	2 86	15.0	2.31	3.43	11.8	2.65	3.80
90	49.8	1.53	1 75	31.2	1.78	2.41	23.5	1.99	2.87	16.9	2.31	3.42	13.3	2.65	3.78
100	55.3	1.53	1 75	34.6	1.78	2.42	26.0	1 97	2.90	18.7	2.29	3.47	14.7	2.63	3.85
110	60.8	1.54	1 75	38.1	1.78	2.41	28.6	1.97	2.90	20.5	2.28	3.50	16.1	2.60	3 90
120	66.3	1.54	1.75	41.5	1 78	2.42	31.2	1 98	2.90	22.4	2.29	3 49	17.5	2 58	3.94
130	71 7	1.53	1.76	44.9	1 78	2.42	33.7	1 97	2 92	24 2	2.28	3 51	18.9	2.57	3.98
140	77 2	1.54	1 76	48.3	1 78	2.43	36.3	1 97	2 92	26.0	2.27	3.54	20.4	2 58	3 95
150	82.6	1.54	1.76	51 7	1.78	2.43	38.9	1.97	2 91	27.9	2.28	3.52	21.8	2.57	3.98
160	88 0	1.53	1.76	55.1	1.78	2.44	41.4	1 97	2 93	29.7	2 27	3.54	23.2	2 56	4.01
170	93.4	1.53	1 77	58.5	1 78	2 44	44.0	1.97	2.92	31.5	2.26	3.55	24.6	2.55	4.03
180	98.8	1.53	1.77	61 9	1 78	2 44	46.5	1.96	2 94	33.3	2.26	3.57	26.1	2.56	4.01
190	104.2	1.54	1 77	65.3	1 78	2 44	49.1	1.97	2.93	35.2	2.27	3.55	27 5	2.56	4.03
200	109.6	1.54	1.77	68.7	1 78	2.44	51.6	1 96	2 94	37.0	2.26	3.56	28.9	2.55	4.04
220	120.5	1.54	1 77	75.5	1 78	2.44	56.8	1.97	2.93	40.7	2.26	3.56	31 8	2 55	4.04
240	131.3	1.54	1 77	82.3	1.78	2.45	61.9	1.97	2.94	44.3	2.26	3.58	34.6	2.54	4.07
260	142.1	1.54	1 77	89.1	1 78	2.45	67.0	1.97	2.94	48.0	2 26	3.58	37.5	2.55	4.06
280	152.9	1.54	1 78	95.9	1.78	2.45	72.1	1.97	2.95	51.6	2.25	3.59	40.3	2.54	4.08
300	163.7	1.54	1.78	102.6	1.78	2.46	77.2	1.97	2.95	55.3	2.26	3.59	43.2	2 54	4.08

Q cfs	V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15												
20												
25												
30												
35												
40												
45												
50												
55												
60												
65												
70												
75												
80												
90												
100	11.9	3.02	4 13									
110	13.0	2.98	4.22									
120	14.1	2.94	4.30									
130	15.2	2.91	4 36									
140	16.4	2.93	4.34									
150	17 5	2 90	4.39	14.0	3.34	4.77						
160	18 6	2.88	4.44	14.9	3.33	4.80						
170	19 8	2.89	4.41	15.7	3.27	4.92						
180	20.9	2.88	4 45	16.6	3.26	4.94						
190	22.0	2.86	4.49	17.5	3.26	4.96						
200	23.1	2.85	4.52	18.4	3.25	4.98	15.3	3.72	5.23			
220	25.4	2.85	4.53	20.2	3.24	5.01	16.7	3.66	5.36			
240	27.7	2.85	4.53	22.0	3.23	5.04	18.2	3.65	5.38			
260	30.0	2.85	4.54	23.8	3.22	5.06	19.7	3.64	5.39			
280	32.2	2.83	4.58	25.6	3.21	5.08	21.1	3.61	5.48	17.5	4.14	5.75
300	34.5	2.83	4.58	27.3	3.18	5.15	22.6	3.60	5.49	18.7	4.12	5.80

Table 4-3 (Continued).

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "C"

Grade 0.75 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	11.7	1.29	1.47	6.8	1.61	2.02									
20	15.5	1.27	1.51	8.9	1.54	2.15									
25	19.3	1.26	1.52	11.0	1.50	2.23	8.2	1.74	2.58						
30	23.1	1.25	1.54	13.2	1.50	2.24	9.7	1.69	2.70	7.7	1.92	2.99			
35	27.0	1.26	1.53	15.3	1.48	2.29	11.3	1.68	2.72	8.9	1.88	3.08			
40	30.8	1.26	1.53	17.5	1.49	2.28	12.8	1.65	2.80	10.1	1.86	3.16			
45	34.5	1.25	1.55	19.6	1.47	2.31	14.4	1.65	2.80	11.3	1.84	3.21			
50	38.3	1.25	1.55	21.8	1.48	2.30	15.9	1.63	2.85	12.5	1.82	3.26	9.3	2.18	3.65
55	42.1	1.25	1.55	24.0	1.48	2.29	17.5	1.64	2.85	13.7	1.81	3.30	10.1	2.12	3.80
60	45.9	1.25	1.55	26.1	1.48	2.31	19.1	1.64	2.84	15.0	1.82	3.26	11.0	2.12	3.82
65	49.6	1.25	1.56	28.2	1.47	2.33	20.6	1.63	2.88	16.2	1.81	3.29	11.9	2.11	3.84
70	53.4	1.25	1.56	30.4	1.48	2.32	22.2	1.63	2.87	17.4	1.80	3.31	12.8	2.11	3.85
75	57.1	1.25	1.56	32.5	1.47	2.33	23.7	1.62	2.90	18.6	1.80	3.34	13.6	2.07	3.95
80	60.9	1.25	1.56	34.7	1.48	2.32	25.3	1.63	2.89	19.8	1.79	3.35	14.5	2.07	3.95
90	68.4	1.25	1.56	38.9	1.47	2.34	28.4	1.62	2.91	22.2	1.78	3.39	16.3	2.07	3.97
100	75.9	1.25	1.56	43.2	1.47	2.34	31.5	1.62	2.92	24.7	1.79	3.37	18.1	2.07	3.98
110	83.4	1.25	1.57	47.5	1.47	2.34	34.7	1.63	2.90	27.1	1.78	3.40	19.8	2.04	4.04
120	90.8	1.25	1.57	51.8	1.47	2.34	37.8	1.62	2.91	29.6	1.79	3.38	21.6	2.05	4.04
130	98.3	1.25	1.57	56.0	1.47	2.35	40.9	1.62	2.92	32.0	1.78	3.40	23.4	2.05	4.04
140	105.7	1.25	1.57	60.3	1.47	2.35	44.0	1.62	2.92	34.4	1.78	3.41	25.1	2.03	4.09
150	113.1	1.25	1.58	64.5	1.47	2.36	47.1	1.62	2.93	36.8	1.77	3.43	26.9	2.04	4.08
160	120.5	1.25	1.58	68.8	1.47	2.35	50.2	1.62	2.93	39.3	1.78	3.41	28.7	2.04	4.07
170	127.9	1.25	1.58	73.0	1.47	2.36	53.3	1.62	2.93	41.7	1.78	3.42	30.4	2.03	4.11
180	135.2	1.25	1.58	77.2	1.47	2.36	56.4	1.62	2.93	44.1	1.78	3.43	32.2	2.03	4.10
190	142.6	1.25	1.58	81.5	1.47	2.36	59.5	1.62	2.93	46.5	1.77	3.43	34.0	2.04	4.09
200	149.9	1.25	1.58	85.7	1.47	2.36	62.5	1.62	2.95	48.9	1.77	3.44	35.7	2.03	4.12
220	164.7	1.25	1.58	94.2	1.47	2.36	68.7	1.62	2.95	53.8	1.78	3.43	39.3	2.03	4.11
240	179.4	1.25	1.59	102.6	1.47	2.37	74.9	1.62	2.95	58.6	1.77	3.44	42.8	2.03	4.12
260	194.1	1.25	1.59	111.1	1.47	2.37	81.1	1.62	2.95	63.5	1.78	3.44	46.3	2.02	4.14
280	208.8	1.25	1.59	119.5	1.47	2.37	87.3	1.62	2.95	68.3	1.77	3.44	49.9	2.03	4.12
300	223.5	1.26	1.59	127.9	1.47	2.37	93.4	1.62	2.96	73.1	1.77	3.45	53.4	2.03	4.13

Q cfs	V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15												
20												
25												
30												
35												
40												
45												
50												
55												
60												
65	9.9	2.38	4.08									
70	10.6	2.35	4.15									
75	11.3	2.33	4.22									
80	12.0	2.31	4.28									
90	13.4	2.28	4.38	11.1	2.62	4.59						
100	14.9	2.28	4.37	12.2	2.56	4.75						
110	16.3	2.26	4.45	13.4	2.55	4.78						
120	17.8	2.26	4.43	14.6	2.54	4.80	12.1	2.85	5.16			
130	19.2	2.24	4.49	15.7	2.51	4.91	13.0	2.81	5.29			
140	20.7	2.25	4.48	16.9	2.51	4.92	14.0	2.81	5.29			
150	22.1	2.23	4.52	18.1	2.50	4.92	15.0	2.81	5.30			
160	23.6	2.24	4.50	19.3	2.50	4.93	15.9	2.77	5.40	13.1	3.13	5.80
170	25.0	2.23	4.54	20.4	2.48	5.00	16.9	2.78	5.39	13.9	3.12	5.83
180	26.5	2.24	4.52	21.6	2.48	5.00	17.8	2.75	5.48	14.7	3.11	5.85
190	27.9	2.23	4.56	22.8	2.48	5.00	18.8	2.75	5.46	15.5	3.11	5.87
200	29.4	2.23	4.54	24.0	2.49	4.99	19.7	2.73	5.54	16.3	3.10	5.88
220	32.3	2.23	4.55	26.3	2.47	5.05	21.7	2.74	5.52	17.9	3.09	5.92
240	35.2	2.23	4.56	28.7	2.47	5.04	23.6	2.72	5.57	19.4	3.05	6.04
260	38.1	2.23	4.57	31.0	2.46	5.09	25.5	2.71	5.61	21.0	3.05	6.05
280	41.0	2.22	4.58	33.4	2.46	5.08	27.4	2.70	5.65	22.6	3.04	6.07
300	43.9	2.22	4.58	35.8	2.47	5.07	29.4	2.71	5.62	24.2	3.04	6.08

Table 4-3 (Continued).

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 1.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	13.4	1.13	1.47	8.4	1.30	2.03																					
20	17.8	1.12	1.49	11.1	1.27	2.10	7.6	1.52	2.55																		
25	22.2	1.11	1.50	13.9	1.27	2.09	9.4	1.49	2.64	7.6	1.62	2.99															
30	26.6	1.11	1.50	16.6	1.26	2.13	11.2	1.46	2.71	9.1	1.61	3.03															
35	30.9	1.11	1.52	19.3	1.25	2.15	13.0	1.45	2.75	10.5	1.57	3.14	8.0	1.80	3.59												
40	35.3	1.11	1.52	22.1	1.26	2.13	14.8	1.44	2.79	12.0	1.57	3.14	9.1	1.78	3.65												
45	39.7	1.11	1.52	24.8	1.25	2.15	16.7	1.45	2.76	13.4	1.55	3.21	10.2	1.76	3.70												
50	44.0	1.11	1.52	27.5	1.25	2.16	18.5	1.44	2.79	14.9	1.55	3.21	11.3	1.75	3.74	8.7	2.02	4.20									
55	48.3	1.11	1.53	30.2	1.25	2.16	20.3	1.43	2.80	16.3	1.54	3.26	12.4	1.75	3.76	9.5	1.99	4.30									
60	52.7	1.11	1.52	32.9	1.25	2.17	22.1	1.43	2.82	17.8	1.54	3.25	13.5	1.74	3.79	10.4	2.01	4.26									
65	57.0	1.11	1.53	35.6	1.25	2.17	23.9	1.43	2.83	19.2	1.53	3.29	14.6	1.73	3.81	11.2	1.98	4.33	9.3	2.22	4.66						
70	61.3	1.11	1.53	38.3	1.25	2.17	25.7	1.43	2.84	20.7	1.53	3.27	15.6	1.71	3.90	12.0	1.96	4.40	10.0	2.21	4.69						
75	65.6	1.11	1.53	41.0	1.25	2.18	27.5	1.42	2.85	22.1	1.53	3.31	16.7	1.71	3.90	12.8	1.95	4.46	10.7	2.21	4.71						
80	69.8	1.11	1.54	43.7	1.25	2.18	29.3	1.42	2.85	23.6	1.53	3.29	17.8	1.71	3.91	13.7	1.96	4.42	11.3	2.16	4.85						
90	78.5	1.11	1.54	49.1	1.25	2.18	32.9	1.42	2.87	26.5	1.53	3.31	20.0	1.70	3.93	15.3	1.93	4.52	12.7	2.16	4.87	10.6	2.42	5.20			
100	87.1	1.11	1.54	54.5	1.25	2.18	36.6	1.43	2.85	29.4	1.52	3.32	22.2	1.70	3.94	17.0	1.93	4.52	14.1	2.15	4.89	11.7	2.39	5.31			
110	95.6	1.11	1.54	59.9	1.25	2.18	40.2	1.42	2.86	32.3	1.52	3.33	24.4	1.70	3.94	18.7	1.93	4.52	15.4	2.12	5.00	12.9	2.40	5.28	11.1	2.59	5.67
120	104.2	1.11	1.54	65.2	1.25	2.19	43.8	1.42	2.87	35.2	1.52	3.33	26.6	1.70	3.95	20.3	1.92	4.59	16.8	2.12	5.00	14.0	2.37	5.36	12.1	2.59	5.69
130	112.7	1.11	1.55	70.6	1.25	2.19	47.4	1.42	2.87	38.1	1.52	3.34	28.8	1.70	3.95	22.0	1.92	4.58	18.2	2.13	5.00	15.1	2.35	5.44	13.0	2.55	5.83
140	121.2	1.11	1.55	76.0	1.25	2.19	51.0	1.42	2.87	41.0	1.52	3.34	30.9	1.69	3.99	23.7	1.92	4.57	19.6	2.13	5.00	16.2	2.34	5.50	14.0	2.55	5.83
150	129.7	1.11	1.55	81.3	1.25	2.19	54.6	1.42	2.87	43.9	1.52	3.34	33.1	1.69	3.99	25.3	1.91	4.62	20.9	2.11	5.07	17.4	2.35	5.46	15.0	2.55	5.84
160	138.1	1.11	1.55	86.6	1.25	2.20	58.2	1.42	2.88	46.8	1.52	3.34	35.3	1.69	3.99	27.0	1.91	4.61	22.3	2.11	5.06	18.5	2.33	5.51	15.9	2.52	5.95
170	146.6	1.11	1.55	91.9	1.25	2.20	61.7	1.42	2.89	49.7	1.52	3.34	37.5	1.69	3.99	28.7	1.92	4.60	23.7	2.11	5.05	19.6	2.32	5.56	16.9	2.52	5.94
180	155.0	1.11	1.55	97.2	1.25	2.20	65.3	1.42	2.89	52.5	1.52	3.36	39.6	1.69	4.01	30.3	1.91	4.63	25.0	2.10	5.10	20.7	2.31	5.60	17.9	2.52	5.93
190	163.4	1.11	1.55	102.5	1.25	2.20	68.9	1.42	2.89	55.4	1.52	3.36	41.8	1.69	4.01	32.0	1.91	4.62	26.4	2.10	5.09	21.9	2.32	5.56	18.8	2.50	6.02
200	171.7	1.11	1.56	107.8	1.25	2.20	72.4	1.42	2.90	58.3	1.52	3.35	44.0	1.69	4.00	33.6	1.91	4.65	27.8	2.11	5.08	23.0	2.32	5.59	19.8	2.50	6.01
220	188.7	1.11	1.56	118.4	1.25	2.21	79.6	1.42	2.89	64.0	1.52	3.37	48.4	1.70	4.00	37.0	1.91	4.63	30.5	2.10	5.12	25.3	2.32	5.59	21.7	2.48	6.08
240	205.5	1.11	1.56	129.0	1.25	2.21	86.7	1.42	2.90	69.8	1.52	3.37	52.7	1.69	4.01	40.3	1.91	4.65	33.3	2.10	5.11	27.5	2.30	5.65	23.6	2.47	6.13
260	222.4	1.11	1.56	139.6	1.25	2.21	93.9	1.42	2.90	75.5	1.52	3.38	57.1	1.69	4.01	43.6	1.91	4.66	36.0	2.10	5.14	29.8	2.30	5.64	25.6	2.48	6.11
280	239.1	1.11	1.56	150.2	1.25	2.22	101.0	1.42	2.91	81.3	1.52	3.37	61.4	1.69	4.02	46.9	1.90	4.68	38.8	2.10	5.12	32.1	2.31	5.63	27.5	2.47	6.15
300	255.9	1.11	1.56	160.8	1.25	2.22	108.1	1.42	2.91	87.0	1.52	3.38	65.7	1.69	4.03	50.3	1.91	4.66	41.5	2.10	5.14	34.3	2.30	5.68	29.5	2.48	6.12

Table 4-3 (Continued).

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 1.25 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	15.3	1.00	1.45	9.8	1.15	1.95	6.6	1.37	2.44						
20	20.4	1.00	1.45	12.9	1.12	2.04	8.7	1.33	2.55	6.6	1.49	2.98			
25	25.4	0.99	1.47	16.1	1.12	2.05	10.8	1.31	2.61	8.2	1.47	3.06	6.7	1 62	3.38
30	30.5	1.00	1.46	19.3	1.12	2.06	12.9	1.30	2.66	9.7	1.43	3.20	7.9	1.56	3.58
35	35.5	0.99	1.47	22.5	1.12	2.06	15.0	1.29	2.68	11.3	1.42	3.22	9.2	1.55	3.62
40	40.5	0.99	1.47	25.7	1.12	2.06	17.1	1.28	2.70	12.9	1.42	3.24	10.5	1.55	3.64
45	45.5	0.99	1.48	28.8	1.11	2.08	19.2	1.28	2.72	14.4	1.40	3.31	11.7	1.52	3.75
50	50.4	0.99	1.49	32.0	1.12	2.08	21.3	1.28	2.73	16.0	1.40	3.31	13.0	1.52	3.75
55	55.4	0.99	1.48	35.1	1.11	2.09	23.4	1.28	2.74	17.6	1.40	3.31	14.3	1.52	3.75
60	60.3	0.99	1.49	38.3	1.12	2.09	25.5	1.28	2.74	19.1	1.39	3.36	15.6	1.52	3.75
65	65.2	0.99	1.49	41.4	1.11	2.10	27.6	1.28	2.74	20.7	1.39	3.35	16.8	1.51	3.81
70	70.1	0.99	1.50	44.6	1.12	2.09	29.7	1.28	2.75	22.3	1.39	3.35	18.1	1.51	3.80
75	75.0	0.99	1.50	47.7	1.12	2.09	31.8	1.28	2.75	23.8	1.39	3.38	19.4	1.51	3.80
80	79.9	0.99	1.50	50.8	1.12	2.10	33.8	1.27	2.77	25.4	1.39	3.37	20.6	1.50	3 84
90	89.7	0.99	1.50	57.1	1.12	2.10	38.0	1.27	2.77	28.5	1.38	3.39	23.2	1.51	3.83
100	99.6	0.99	1.50	63.3	1.11	2.11	42.2	1.27	2.77	31.7	1.39	3.38	25.7	1.50	3.86
110	109.4	0.99	1.50	69.6	1.12	2.11	46.4	1.27	2.77	34.8	1.39	3.39	28.3	1.50	3.85
120	119.1	0.99	1.51	75.8	1.12	2.11	50.5	1.27	2.78	37.9	1.38	3.41	30.8	1.50	3.87
130	128.9	1.00	1.51	82.0	1.12	2.11	54.7	1.27	2.78	41.1	1.39	3.39	33.3	1.49	3.89
140	138.6	1.00	1.51	88.2	1.12	2.12	58.8	1.27	2.79	44.2	1.39	3.40	35.9	1 50	3.87
150	148.2	1.00	1.51	94.4	1.12	2.12	63.0	1.27	2.78	47.3	1.39	3.41	38.4	1.50	3.88
160	157.9	1.00	1.51	100.6	1.12	2.12	67.1	1.27	2.79	50.4	1 39	3.41	40.9	1 50	3.89
170	167.5	1.00	1.51	106.7	1.12	2.12	71.2	1.27	2.79	53.5	1.39	3.41	43.4	1.49	3 90
180	177.1	1.00	1.51	112.9	1.12	2.12	75.3	1.27	2.80	56.6	1.39	3.42	46.0	1.50	3.88
190	186.6	1.00	1.52	119.0	1.12	2.12	79.4	1.27	2.80	59.7	1.39	3.42	48.5	1.50	3.89
200	196.1	1.00	1.52	125.1	1.12	2.13	83.5	1.27	2.80	62.8	1.39	3.42	51.0	1.50	3.90
220	215.4	1.00	1.52	137.4	1.12	2.13	91.8	1.27	2.80	69.0	1.39	3.42	56.0	1.50	3.91
240	234.7	1.00	1.52	149.8	1.12	2.13	100.0	1.27	2.81	75.2	1.39	3.43	61.1	1.50	3.90
260	253.8	1 00	1.52	162.0	1.12	2.13	108.2	1.27	2.81	81.4	1.39	3.43	66.1	1.50	3.91
280	273.0	1.00	1.52	174.3	1.12	2.13	116.4	1.27	2.81	87.6	1.39	3.43	71.1	1.50	3.92
300	292.0	1.00	1.53	186.5	1.12	2.14	124.6	1.27	2.82	93.7	1.39	3.44	76.2	1.50	3.91

Q cfs	V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15												
20												
25												
30												
35	7.2	1.78	4.02									
40	8.2	1.77	4.07									
45	9.1	1.72	4.25									
50	10.1	1.71	4.27	8.3	1.95	4.57						
55	11.1	1.71	4.29	9.1	1.93	4.63						
60	12.1	1.71	4.30	9.9	1.92	4.67						
65	13.0	1.68	4.41	10.6	1.88	4.84	8.7	2.18	5.06			
70	14.0	1.68	4.41	11.4	1.87	4.86	9.3	2.15	5.18			
75	15.0	1.68	4.40	12.2	1.87	4.88	9.9	2.12	5.28			
80	16.0	1.69	4.40	13.0	1.87	4.89	10.5	2.10	5.37	9.2	2.33	5.51
90	17.9	1 67	4.48	14.6	1.86	4.92	11 8	2.09	5.40	10.3	2.31	5.60
100	19.9	1.67	4.47	16.2	1.85	4.94	13.1	2.09	5.42	11.4	2.29	5.68
110	21.9	1.67	4.46	17.8	1.85	4.96	14.4	2.09	5.43	12.4	2.24	5.88
120	23.8	1.66	4.51	19.3	1.83	5.05	15.6	2.06	5.55	13.5	2.23	5.91
130	25.8	1.67	4.50	20.9	1.83	5.05	16.9	2.06	5.55	14.6	2.22	5.95
140	27.8	1.67	4.48	22.5	1.83	5.06	18.2	2.06	5.55	15.7	2.22	5.97
150	29.7	1.66	4.52	24.1	1.83	5.06	19.4	2.04	5.63	16.8	2.21	6.00
160	31.7	1.67	4.51	25.7	1.83	5.06	20.7	2.05	5.62	17.9	2.21	6.01
170	33.6	1.66	4.53	27.3	1.83	5.06	22.0	2.05	5.62	19.0	2.21	6.03
180	35.6	1.67	4.52	28.9	1.84	5.05	23.3	2.05	5.61	20.1	2.21	6.04
190	37.5	1 66	4.54	30.4	1.83	5.10	24.5	2.04	5.67	21.2	2.20	6.05
200	39.5	1.67	4.52	32.0	1.83	5.09	25.8	2.04	5.66	22.3	2.20	6.06
220	43.4	1.67	4.53	35.2	1.83	5.09	28.3	2.03	5.70	24.5	2.20	6.08
240	47.3	1.67	4.54	38.4	1.83	5.09	30.9	2.04	5.68	26.7	2.20	6.10
260	51.2	1.66	4.55	41.5	1.83	5.12	33.4	2.03	5.72	28.8	2.18	6.18
280	55.1	1.67	4.55	44.7	1.83	5.11	36.0	2.03	5.70	31.0	2.18	6.18
300	59.0	1.67	4.55	47.8	1.82	5.13	38.5	2.03	5.73	33.2	2.18	6.19

Table 4-3 (Continued).

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 1.50 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	17.0	0.92	1.42	11.3	1.05	1.86	7.6	1.20	2.41																		
20	22.7	0.92	1.41	14.9	1.03	1.93	10.0	1.17	2.53	7.0	1.40	3.01	5.7	1.52	3.39												
25	28.3	0.92	1.42	18.6	1.03	1.94	12.4	1.15	2.59	8.6	1.35	3.19	7.0	1.46	3.60												
30	33.9	0.92	1.43	22.3	1.03	1.94	14.9	1.15	2.59	10.3	1.34	3.22	8.4	1.46	3.62	6.9	1.59	4.03									
35	39.5	0.92	1.43	26.0	1.03	1.95	17.3	1.14	2.62	11.9	1.31	3.32	9.7	1.43	3.74	8.0	1.56	4.13									
40	45.0	0.92	1.44	29.7	1.03	1.94	19.8	1 15	2.61	13 6	1 31	3.32	11.1	1.43	3.73	9.1	1.55	4.20	7.1	1.79	4.64						
45	50.5	0.92	1.44	33.3	1.02	1.96	22.2	1.14	2.63	15.2	1.30	3.39	12.4	1.41	3.81	10.2	1.54	4.25	8.0	1.79	4.63						
50	56.1	0.92	1.44	37.0	1.03	1.95	24.6	1.14	2.65	16.9	1.30	3.38	13.7	1.39	3.88	11.3	1.53	4.29	8.8	1.75	4.78						
55	61.5	0.92	1.45	40.6	1.02	1.96	27.1	1.14	2.64	18.6	1.30	3.37	15.1	1.40	3.86	12.4	1.52	4.32	9.6	1.73	4.91	8.2	1.93	5.14			
60	67.0	0.92	1.45	44.2	1.02	1.97	29.5	1.14	2.65	20.2	1.29	3.41	16.4	1.39	3.91	13.5	1.52	4.35	10.5	1.73	4.88	8.9	1.91	5.23			
65	72.5	0.92	1.45	47.8	1.02	1.98	31.9	1.14	2.66	21.9	1.30	3.40	17.8	1.40	3.88	14.6	1.51	4.37	11.3	1.71	4.97	9.6	1.89	5.30			
70	77.9	0.92	1.45	51.4	1.02	1.98	34.3	1.14	2.66	23.5	1.29	3.43	19.1	1.39	3.92	15.7	1.51	4.39	12.2	1.72	4.94	10.3	1.88	5.36	8.8	2.12	5.55
75	83.3	0.92	1.46	55.0	1.02	1.98	36.7	1.14	2.67	25.2	1.29	3.42	20.5	1.40	3.89	16.8	1.51	4.40	13.0	1.70	5.02	11.0	1.87	5.41	9.4	2.10	5.61
80	88.7	0.92	1.46	58.6	1.02	1.98	39.1	1.14	2.67	26.8	1.29	3.44	21.8	1.39	3.93	17.9	1.50	4.41	13.9	1.71	4.98	11.7	1.86	5.46	9.9	2.05	5.83
90	99.6	0.92	1.46	65.8	1.02	1.99	44.0	1.14	2.66	30.1	1.29	3.46	24.5	1.39	3.93	20.1	1.50	4.43	15.6	1.71	5.02	13.2	1.87	5.42	11.1	2.04	5.90
100	110.5	0.92	1.46	73.0	1.02	1.99	48.8	1.14	2.67	33.4	1.29	3.47	27.2	1.39	3.94	22.3	1.50	4.45	17.3	1.70	5.05	14.6	1.85	5.50	12.3	2.03	5.95
110	121.4	0.92	1.46	80.2	1.02	1.99	53.6	1.14	2.68	36.7	1.28	3.47	29.9	1.39	3.94	24.5	1.50	4.46	19.0	1.70	5.07	16.0	1.84	5.56	13.5	2.02	6.00
120	132.2	0.92	1.46	87.3	1.02	2.00	58.4	1.14	2 68	40.0	1.28	3.48	32.6	1.39	3.95	26.7	1 49	4.47	20.7	1.69	5.09	17.5	1.85	5.52	14.7	2.01	6.03
130	142.9	0.92	1.47	94.5	1.02	2.00	63.2	1.14	2.68	43.3	1.29	3.48	35.3	1.39	3.94	28.9	1.49	4.48	22.4	1.69	5.10	18.9	1.84	5.57	15.9	2.00	6.06
140	153.6	0.92	1.47	101.6	1.02	2.00	68.0	1.14	2.69	46.6	1.29	3.48	37.9	1.38	3.97	31.1	1.49	4.48	24.0	1.68	5.18	20.3	1.83	5.61	17.1	2.00	6.08
150	164.3	0.92	1.47	108.7	1.03	2.00	72.8	1.14	2.68	49.9	1.29	3.48	40.6	1.39	3.97	33.3	1.49	4.49	25.7	1.68	5.18	21.7	1.82	5.64	18.3	2.00	6.10
160	175.0	0.92	1.47	115.7	1.02	2.01	77.6	1.14	2.68	53.2	1.29	3.48	43.3	1.39	3.97	35.5	1.50	4.49	27.4	1.68	5.19	23.2	1.83	5.60	19.5	1.99	6.12
170	185.6	0.92	1.48	122.8	1.03	2.01	82.3	1.14	2.69	56.4	1.29	3.49	45.9	1.38	3.99	37.7	1.50	4.49	29.1	1.68	5.19	24.6	1.83	5.63	20.7	1.99	6.13
180	196.2	0.92	1.48	129.8	1.02	2.01	87.1	1.14	2.69	59.7	1.29	3.49	48.6	1.39	3.98	39.8	1.49	4.52	30.8	1.68	5.19	26.0	1.82	5.66	21.9	1.99	6.14
190	206.7	0.92	1.48	136.8	1.03	2.02	91.8	1.14	2.69	62.9	1.29	3.50	51.3	1.39	3.97	42.0	1.49	4.52	32.5	1.68	5.18	27.4	1.82	5.68	23.1	1.99	6.15
200	217.2	0.92	1.48	143.8	1.03	2.02	96.5	1.14	2.70	66.2	1.29	3.49	53.9	1.39	3.99	44.2	1.49	4.51	34.2	1.68	5.18	28.9	1.83	5.64	24.3	1.99	6.16
220	238.5	0.92	1.48	157.9	1.03	2.02	106.0	1.14	2.70	72.7	1.29	3.50	59.3	1.39	3.98	48.6	1.50	4.51	37.6	1.68	5.19	31.7	1.82	5.68	26.7	1.99	6.18
240	259.7	0.92	1.49	172.0	1.03	2.02	115.6	1.15	2.70	79.3	1.29	3.50	64.6	1.39	3.99	53.0	1.50	4.51	40.9	1.67	5.23	34.6	1.82	5.67	29.1	1.98	6.19
260	280.9	0.92	1.49	186.1	1.03	2.03	125.0	1.15	2.71	85.8	1.29	3.51	69.9	1.39	3.99	57.3	1.49	4.53	44.3	1.68	5.22	37.4	1.82	5.70	31.5	1.98	6.20
280	302.0	0.92	1.49	200.1	1.03	2.03	134.5	1.15	2.71	92.3	1.29	3.51	75.2	1.39	4.00	61.7	1.50	4.53	47.7	1.68	5.22	40.3	1.82	5.69	33.9	1.98	6.21
300	323.0	0.93	1.49	214.1	1.03	2.03	143.9	1.15	2.71	98.8	1.29	3.51	80.5	1.39	4.00	66.0	1.49	4.54	51.1	1.68	5.21	43.1	1.82	5.71	36.3	1.98	6.21

Table 4-3 (Continued).

V_1 for RETARDANCE "D" Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 1.75 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	18.5	0.87	1.38	12.1	0.97	1.89	8.5	1.08	2.40	5.9	1.28	2.92															
20	24.5	0.86	1.41	16.1	0.96	1.91	11.3	1.07	2.43	7.8	1.25	3.03	6.5	1.34	3.38												
25	30.6	0.86	1.41	20.1	0.96	1.91	14.1	1.07	2.45	9.7	1.23	3.09	8.1	1.33	3.43	6.6	1.46	3.81									
30	36.7	0.86	1.40	24.1	0.96	1.92	16.8	1.06	2.50	11.6	1.22	3.13	9.6	1.29	3.57	7.8	1.41	4.01									
35	42.7	0.86	1.41	28.1	0.96	1.92	19.6	1.06	2.50	13.4	1.20	3.23	11.2	1 29	3.58	9.1	1.41	4.02	7.1	1.59	4.57						
40	48.7	0.86	1.42	32.0	0.96	1.93	22.4	1.06	2.50	15.3	1.20	3.24	12.7	1 27	3.67	10.3	1.38	4.15	8.1	1.58	4.61						
45	54.7	0.86	1.42	36.0	0.96	1.93	25.1	1.05	2.53	17.2	1.20	3.24	14.3	1.28	3.66	11.6	1.39	4.14	9.1	1 57	4.64	7.5	1.73	5.12			
50	60.7	0.86	1.42	39.9	0.96	1.94	27.9	1.06	2.52	19.1	1.20	3.25	15.8	1.26	3.72	12.8	1.37	4 22	10.0	1.54	4.80	8.3	1.71	5.20			
55	66.6	0.86	1.42	43.8	0.96	1.94	30.6	1.05	2.53	21.0	1 20	3.25	17.4	1.27	3.70	14.1	1.37	4.21	11 0	1.54	4.80	9.1	1.70	5.25	7.5	1.91	5.65
60	72.5	0.86	1.43	47.7	0.96	1.95	33.3	1.05	2.55	22.8	1.19	3.29	18.9	1.26	3.75	15.4	1.38	4.19	12.0	1.54	4.81	9.9	1.69	5.30	8.2	1.92	5.63
65	78.4	0.86	1.43	51.6	0.96	1.95	36.1	1.06	2.54	24.7	1.19	3.28	20.5	1.26	3.73	16.6	1.37	4.25	12.9	1.52	4.92	10.7	1.68	5.34	8.8	1.88	5.79
70	84.3	0.86	1.43	55.5	0.96	1.95	38.8	1.05	2 54	26.6	1.19	3.28	22.0	1.26	3.76	17.9	1.37	4.23	13.9	1.52	4.91	11.5	1.68	5.38	9.5	1.89	5.76
75	90.2	0.86	1.43	59.4	0.96	1 95	41.5	1.05	2 55	28.5	1.20	3.27	23.6	1.26	3.74	19.1	1.36	4.28	14.9	1.52	4.90	12.3	1.67	5.40	10.1	1.87	5.89
80	96.0	0.86	1.43	63.2	0.96	1.96	44.2	1.05	2 56	30.3	1 19	3.30	25.1	1.26	3.77	20.4	1.37	4.25	15.9	1 53	4.89	13.1	1.67	5.43	10.8	1.88	5.85
90	107.8	0.86	1.44	71.0	0.96	1.96	49 7	1.05	2 55	34.1	1.19	3.29	28.2	1.26	3.78	22.9	1.37	4.28	17.8	1.51	4.96	14.7	1 66	5.47	12.1	1.86	5.93
100	119.5	0.86	1.44	78.8	0.96	1 96	55.1	1.05	2 56	37.8	1.19	3.31	31.3	1.26	3 79	25.4	1.36	4.30	19.8	1.52	4.94	16.3	1.65	5.51	13.4	1.85	5.99
110	131.2	0.86	1.44	86.5	0.96	1.97	60.5	1.05	2.57	41.5	1.19	3.32	34.4	1.26	3.79	27.9	1.36	4.31	21.7	1.51	4.99	17 9	1.65	5.53	14.7	1.84	6.05
120	142.9	0.86	1.44	94.2	0.96	1 97	65.9	1.05	2 58	45.3	1.19	3.31	37.5	1 26	3.79	30.4	1.36	4.32	23.7	1.51	4.97	19 5	1.65	5.55	16.0	1.83	6.09
130	154.5	0.86	1.45	101.9	0.96	1 97	71.3	1.05	2 58	49.0	1.19	3.31	40.6	1 26	3.79	32.9	1.36	4.33	25.6	1.51	5.01	21.1	1.65	5.57	17.3	1.82	6.12
140	166.1	0.87	1.45	109.6	0.96	1.97	76.7	1.05	2 58	52.7	1.19	3.32	43.7	1.26	3.79	35.4	1.36	4.33	27.6	1.51	4.99	22.7	1.64	5.58	18.6	1.82	6.15
150	177.6	0.87	1.45	117.2	0.96	1 98	82.1	1 05	2 58	56.4	1.19	3.32	46.8	1 26	3.79	37.9	1.36	4.33	29.5	1.51	5.02	24.3	1.64	5 59	19 9	1.82	6.17
160	189.1	0.87	1.45	124.8	0.96	1.98	87.5	1.06	2 58	60.1	1.19	3.33	49.8	1.26	3.81	40.4	1.36	4.33	31.4	1.50	5.04	25.9	1.64	5.60	21.3	1.83	6.10
170	200.5	0.87	1.45	132.4	0.96	1 98	92.8	1.05	2.58	63.7	1 19	3.34	52.9	1.26	3.80	42.9	1.36	4.33	33.4	1.51	5.02	27.5	1.64	5.60	22,6	1.83	6.13
180	211.9	0.87	1.46	140.0	0.96	1 98	98.1	1.05	2.59	67.4	1.19	3.34	55.9	1.26	3.82	45.4	1.36	4.33	35.3	1.51	5.04	29.1	1.64	5.61	23.9	1.83	6.14
190	223.3	0.87	1.46	147.5	0.96	1.99	103.4	1.05	2 59	71.1	1.19	3.34	59.0	1 26	3.81	47.8	1.36	4.36	37.2	1.50	5.06	30.7	1.64	5.61	25.2	1 82	6.16
200	234.6	0.87	1 46	155.1	0.97	1.99	108.7	1.06	2.60	74.7	1.19	3.35	62.0	1.26	3.82	50.3	1.36	4.35	39.2	1.51	5.03	32.3	1.64	5.61	26.5	1.82	6.17
220	257 6	0.87	1.46	170.3	0.96	1.99	119.4	1.06	2.60	82.1	1.19	3.35	68.1	1.26	3.83	55.3	1.36	4.35	43.1	1.51	5.03	35.5	1.64	5.62	29.1	1.82	6.20
240	280.4	0.87	1.47	185.5	0.97	1.99	130.1	1.06	2.60	89.5	1 19	3.35	74.3	1.26	3.82	60.3	1.36	4.35	46.9	1.51	5.06	38.7	1.64	5.62	31.7	1.81	6.22
260	303.2	0.87	1.47	200.6	0.97	2.00	140.8	1.06	2.60	96.9	1.19	3.35	80.4	1.26	3.82	65.2	1.36	4.37	50.8	1.51	5.06	41.9	1.64	5.63	34.3	1.81	6.24
280	326.0	0.87	1.47	215.7	0.97	2.00	151.4	1.06	2.61	104.2	1.19	3.36	86.5	1.26	3.83	70.2	1 36	4.36	54.7	1.51	5.05	45.1	1.64	5.63	36.9	1.81	6.25
300	348.6	0.87	1.47	230.8	0.97	2.00	162.0	1.06	2.61	111.5	1.19	3.36	92.5	1.26	3.84	75.1	1.36	4.37	58.5	1.51	5.07	48.3	1.65	5 63	39.5	1.81	6.26

Table 4-3 (Continued).

V_1 for RETARDANCE "D". - Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 2.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	20.8	0.81	1.32	12.8	0.91	1.90	9.3	1.00	2.37	6.7	1.15	2.85
20	27.6	0.80	1.33	17.1	0.91	1.89	12.3	0.99	2.43	8.8	1.12	3.00
25	34.5	0.81	1.33	21.3	0.91	1.91	15.4	0.99	2.43	11.0	1.11	3.01
30	41.3	0.81	1.34	25.5	0.91	1.92	18.4	0.98	2.46	13.2	1.11	3.02
35	48.0	0.80	1.35	29.7	0.91	1.93	21.5	0.99	2.44	15.3	1.10	3.08
40	54.8	0.80	1.34	33.9	0.91	1.93	24.5	0.98	2.46	17.5	1.10	3.07
45	61.5	0.80	1.35	38.1	0.91	1.93	27.5	0.98	2.47	19.6	1.10	3.11
50	68.2	0.80	1.35	42.3	0.91	1.93	30.5	0.98	2.48	21.8	1.10	3.09
55	74.9	0.81	1.35	46.4	0.91	1.94	33.5	0.98	2.48	23.9	1.09	3.12
60	81.5	0.81	1.36	50.6	0.91	1.93	36.5	0.98	2.49	26.1	1 10	3.10
65	88.1	0.81	1.36	54.7	0.91	1.94	39.5	0.98	2.49	28.2	1.10	3.12
70	94.7	0.81	1.36	58.8	0.91	1.94	42.5	0.98	2.49	30.3	1.09	3.14
75	101.2	0.81	1.36	62.9	0.91	1.94	45.5	0.99	2.49	32.4	1.09	3.15
80	107.8	0.81	1.36	67.0	0.91	1.95	48.4	0.98	2.50	34.6	1.10	3.13
90	121.0	0.81	1.37	75.2	0.91	1.95	54.4	0.98	2.50	38.8	1.09	3.15
100	134.2	0.81	1 37	83.4	0.91	1.96	60.4	0.99	2.50	43.1	1.10	3.15
110	147.3	0.81	1.37	91.6	0.91	1.96	66.3	0.98	2.51	47.4	1.10	3.15
120	160.3	0.81	1.38	99.8	0.91	1.96	72.2	0.98	2.51	51.6	1.10	3.16
130	173.3	0.81	1.38	107.9	0.91	1.96	78 1	0.98	2.51	55.8	1.09	3.17
140	186.3	0.81	1 38	116.0	0.91	1 97	84.0	0.99	2.52	60.1	1.10	3.16
150	199.2	0.81	1 38	124.1	0.91	1.97	89.9	0.99	2.52	64.3	1.10	3.16
160	212.0	0.81	1.38	132.1	0.91	1.97	95.7	0.99	2.52	68.5	1.10	3.17
170	224.8	0.81	1.39	140.2	0.91	1.97	101.6	0.99	2.52	72.7	1.10	3.17
180	237.5	0.81	1.39	148.2	0.91	1.98	107.4	0.99	2.53	76.8	1.10	3.18
190	250.2	0.81	1.39	156.1	0.91	1.98	113.2	0.99	2.53	81.0	1.10	3.18
200	262.8	0.81	1.39	164.1	0.91	1.98	119.0	0.99	2.53	85.2	1.10	3.18
220	288.5	0.81	1.40	180.2	0.91	1.99	130.7	0.99	2.54	93.6	1.10	3.18
240	314.1	0.81	1.40	196.2	0.91	1.99	142.4	0.99	2.54	102.0	1.10	3.19
260	339.5	0.81	1.40	212.2	0.91	1.99	154.0	0.99	2.54	110.3	1.10	3.20
280	364.9	0.81	1.40	228.2	0.92	1.99	165.6	0.99	2.55	118.7	1.10	3.19
300	390.2	0.81	1.40	244.1	0.92	2.00	177.2	0.99	2.55	127.0	1.10	3.20

Q cfs	V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15															
20	6.5	1.29	3.51	5.4	1.41	3.84									
25	8.0	1.25	3.69	6.7	1.38	3.96									
30	9.6	1.24	3.71	7.9	1.33	4.20	6.6	1.49	4.48						
35	11.1	1.22	3.82	9.2	1.33	4.23	7.6	1.45	4.68						
40	12.7	1.22	3.81	10.5	1.32	4.26	8.7	1.45	4.67	7.2	1.65	4.96			
45	14.3	1.23	3.80	11.8	1.32	4.27	9.7	1.43	4.80	8.0	1.61	5.16			
50	15.8	1.22	3.86	13.1	1.32	4.28	10.8	1.43	4.78	8.8	1.57	5.33	7.5	1.74	5.64
55	17.4	1.22	3.84	14.4	1.32	4.29	11.8	1.42	4.87	9.7	1.58	5.30	8.2	1.72	5.75
60	18.9	1.21	3.89	15.6	1.30	4.38	12.9	1.42	4.84	10.6	1.59	5.28	9.0	1.74	5.65
65	20.5	1.22	3.87	16.9	1.30	4.38	13.9	1.41	4.92	11.4	1.56	5.40	9.7	1.73	5.74
70	22.0	1.21	3.90	18.2	1.31	4.37	15.0	1.42	4.89	12.3	1.57	5.37	10.4	1.71	5.82
75	23.6	1.22	3.88	19.5	1.31	4.37	16.0	1.41	4.95	13.1	1.55	5.46	11.1	1.70	5.89
80	25.1	1.21	3.91	20.7	1.30	4.42	17.1	1.41	4.91	14.0	1.56	5.43	11.8	1.69	5.95
90	28.2	1.21	3.92	23.3	1.30	4.41	19.2	1.41	4.94	15.7	1.55	5.48	13.3	1.69	5.92
100	31.3	1.21	3.93	25.9	1.30	4.40	21.3	1.41	4.96	17.4	1.55	5.52	14.7	1.68	6.02
110	34.4	1.21	3.93	28.4	1.30	4.44	23.4	1.40	4.98	19.1	1.54	5.55	16.2	1.68	5.99
120	37.5	1.21	3.93	31.0	1.30	4.42	25.5	1.40	4.99	20.8	1.54	5.58	17.6	1.67	6.06
130	40.6	1.21	3.93	33.5	1.30	4.45	27.6	1.40	5.00	22.5	1.53	5.60	19.1	1 68	6.03
140	43.6	1.21	3.96	36.0	1.29	4.47	29.7	1.40	5.00	24.2	1.53	5.62	20.5	1.67	6.08
150	46.7	1.21	3.96	38.6	1.30	4.45	31.8	1.40	5.00	25.9	1 53	5.63	21.9	1.66	6.13
160	49.8	1 21	3.95	41.1	1.30	4.47	33.8	1.40	5.05	27 6	1.53	5.64	23.4	1.67	6.09
170	52.8	1.21	3.97	43.6	1.30	4.48	35.9	1.40	5.05	29.3	1.53	5.65	24.8	1.66	6.13
180	55.9	1.21	3.96	46.2	1.30	4.46	38.0	1.40	5.04	31.0	1.53	5.65	26.3	1.67	6.10
190	58.9	1.21	3.97	48.7	1.30	4.47	40.1	1.40	5.04	32.7	1.53	5.65	27.7	1.67	6.13
200	61.9	1.21	3.98	51.2	1.30	4.48	42.2	1.40	5.03	34.4	1.53	5.66	29.1	1.66	6.16
220	68.1	1.21	3.97	56.3	1.30	4.48	46.3	1.40	5.06	37.8	1.53	5.67	32.0	1.66	6.16
240	74.2	1.21	3.98	61.3	1.30	4.50	50.5	1.40	5.06	41.2	1.53	5.68	34.9	1.66	6.16
260	80.3	1.21	3.98	66.4	1.30	4.49	54.7	1.40	5.05	44.6	1.53	5.68	37.8	1.66	6.16
280	86.3	1.21	4.00	71.4	1.30	4.50	58.8	1.40	5.07	48.0	1.53	5.68	40.6	1.66	6.20
300	92.4	1.21	4.00	76.4	1.30	4.51	63.0	1.40	5.06	51.4	1.53	5.68	43.5	1.66	6.19

Table 4-3 (Continued).

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 3.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	23.6	0.69	1.35	16.3	0.76	1.80	11.4	0.83	2.33	8.8	0.90	2.77	6.5	1.01	3.37	5.0	1.16	3.78									
20	31.4	0.69	1.36	21.7	0.76	1 81	15.2	0.83	2.34	11 7	0.90	2.81	8.6	0.99	3.48	6.6	1.13	3.94	5.9	1.19	4.17						
25	39.2	0.69	1.36	27.0	0.75	1.83	19.0	0.83	2.33	14.6	0.90	2.83	10.8	0.99	3.44	8.1	1.09	4.18	7.3	1.16	4.33	6.0	1.27	4.80			
30	46.9	0.69	1.37	32.4	0.75	1.82	22.7	0.83	2.36	17.4	0.88	2.89	12.9	0.98	3.49	9.7	1.08	4.22	8.7	1.15	4.44	7.1	1.24	5.03	5.8	1.41	5.37
35	54.6	0.69	1.37	37.7	0.75	1.83	26.4	0.83	2.38	20.3	0.89	2.88	15.0	0.98	3.53	11.3	1.08	4.25	10.1	1.13	4.51	8.3	1.24	5.02	6.7	1.38	5.55
40	62.2	0.69	1.37	43.0	0.75	1.83	30.2	0.83	2.37	23.2	0.89	2.88	17.1	0.98	3.55	12.9	1.08	4.26	11.5	1.13	4.57	9.4	1.22	5.17	7.6	1.36	5.70
45	69.9	0.70	1.37	48.3	0.75	1.83	33.9	0.83	2.37	26.0	0.88	2.90	19.2	0.97	3.57	14.5	1.08	4.27	12.9	1.12	4.61	10.6	1.22	5.14	8.5	1.34	5.81
50	77.4	0.69	1.38	53.5	0.75	1.84	37.6	0.83	2.38	28.9	0.89	2.89	21.3	0.97	3.58	16.0	1.06	4.36	14.3	1.12	4.63	11.7	1.21	5.24	9.4	1.33	5.90
55	85.0	0.70	1.38	58.7	0.75	1.85	41.2	0.83	2.40	31.7	0.89	2.91	23.4	0.97	3.58	17.6	1 06	4.35	15.7	1.11	4.66	12.9	1.21	5.20	10.4	1.35	5.80
60	92.5	0.70	1.38	64.0	0.75	1.84	44.9	0.83	2.40	34.5	0.88	2.92	25.5	0.97	3.59	19.2	1.07	4.35	17.1	1.11	4.67	14.0	1.20	5.28	11.3	1.34	5.87
65	99.9	0.69	1.39	69.1	0.75	1.85	48.6	0.83	2.39	37.3	0.88	2.93	27.6	0.97	3.59	20.8	1.07	4.34	18.5	1.11	4.69	15.2	1.21	5.24	12.2	1.33	5.93
70	107.3	0.69	1.39	74.3	0.75	1.86	52.2	0.83	2.40	40.1	0.88	2.93	29.7	0.98	3.59	22.3	1.06	4.39	19.9	1.11	4.69	16.3	1.20	5.30	13.1	1.32	5.98
75	114.7	0.70	1.39	79.4	0.75	1.86	55.8	0.83	2.41	42.9	0.88	2.94	31.8	0.98	3.59	23.9	1.06	4.38	21.3	1.11	4.70	17.5	1.21	5.26	14.0	1.32	6.02
80	122.1	0.70	1.40	84.5	0.75	1 87	59.4	0.83	2.42	45.7	0.88	2.94	33.9	0.98	3.58	25.5	1.07	4.36	22.7	1.11	4.70	18.6	1.20	5.31	15.0	1.33	5.94
90	137.0	0.70	1.40	94.9	0.75	1.87	66.7	0.83	2.42	51.4	0.89	2.93	38.0	0.97	3.61	28.6	1.06	4.40	25.5	1.11	4.72	20.9	1.20	5.33	16.8	1.32	6.01
100	151.8	0.70	1.40	105.2	0.75	1.87	74.0	0.83	2.42	57 0	0.89	2.94	42.2	0.98	3.61	31.7	1.06	4.42	28.3	1.11	4.73	23.2	1.20	5.34	18.6	1.31	6.08
110	166.6	0.70	1.41	115.5	0.75	1 87	81.3	0.83	2.42	62.6	0.89	2 95	46.4	0.98	3.61	34.9	1.06	4.40	31.0	1.10	4.78	25.5	1.20	5.34	20.5	1.32	6.04
120	181.3	0.70	1.41	125.7	0.75	1.88	88 5	0.83	2.43	68.2	0.89	2.95	50.5	0.98	3 62	38.0	1.06	4.42	33.8	1.11	4.78	27.7	1.19	5.40	22.3	1.32	6.08
130	195.9	0.70	1.41	135.9	0.76	1.88	95.7	0.83	2.43	73.7	0.89	2.96	54.6	0.98	3.63	41.1	1.06	4.43	36.6	1.11	4.77	30.0	1.19	5.40	24.2	1.32	6.04
140	210.5	0.70	1.41	146.1	0.76	1.88	102.8	0.83	2.44	79.3	0.89	2.96	58.8	0.98	3.62	44.2	1.06	4.44	39.4	1.11	4.77	32.3	1.20	5.39	26.0	1.32	6.08
150	225.0	0.70	1.42	156.2	0.76	1.89	110.0	0.83	2.44	84.8	0.89	2.96	62.9	0.98	3.63	47.3	1.06	4.44	42.1	1.11	4.80	34.6	1 20	5.38	27.8	1.31	6.11
160	239.4	0.70	1.42	166.2	0.76	1 89	117.1	0.83	2.45	90.3	0.89	2.97	67.0	0.98	3.63	50.4	1.06	4.45	44.9	1.11	4.79	36.8	1.19	5.42	29.6	1.31	6.13
170	253.7	0.70	1.42	176.2	0.76	1 90	124.2	0.83	2.45	95.8	0.89	2.97	71.1	0.98	3 64	53.5	1.06	4.45	47.7	1.11	4.78	39.1	1.20	5.41	31.5	1.32	6.09
180	268.0	0.70	1.43	186.2	0.76	1.90	131.2	0.83	2.45	101 3	0.89	2.97	75.2	0.98	3.64	56.6	1.06	4.45	50.4	1.11	4.80	41.3	1.19	5.44	33.3	1.32	6.11
190	282.2	0.70	1.43	196.1	0.76	1.90	138.3	0.83	2.45	106.7	0.89	2.98	79.2	0.98	3.65	59.7	1.07	4.45	53.1	1 11	4.81	43.6	1.20	5.42	35.1	1.32	6.12
200	296.3	0.70	1.43	206.0	0.76	1.90	145.3	0.83	2.46	112.2	0.89	2.98	83.3	0.98	3.65	62.7	1.06	4.47	55.9	1.11	4.80	45.8	1.19	5.45	36.9	1.32	6.14
220	325.1	0.70	1.44	226.1	0.76	1.91	159.5	0.83	2.47	123 2	0.89	2.98	91.5	0.98	3.65	68.9	1.06	4.47	61.4	1.11	4.81	50.4	1.20	5.43	40.6	1.32	6.12
240	353.8	0.70	1.44	246.2	0.76	1 91	173.7	0.83	2.47	134 2	0.89	2.99	99.7	0.98	3.65	75.1	1.07	4.47	66.9	1 11	4.81	54.9	1.20	5.44	44.2	1.32	6.15
260	382.4	0.70	1.44	266.1	0.76	1.92	187 8	0.83	2.48	145.1	0.89	2.99	107.8	0.98	3.67	81.3	1.07	4.47	72.4	1.11	4.82	59.4	1.20	5.45	47.8	1.31	6.17
280	410.8	0.70	1.45	286.0	0.76	1.92	201 9	0.83	2.48	156.0	0.89	3.00	116.0	0.98	3.66	87.4	1.07	4.48	77.9	1.11	4.82	63.9	1.20	5.46	51.5	1.32	6.15
300	439.0	0.70	1.45	305.8	0.76	1.92	215.9	0.83	2.49	166.9	0.89	3.00	124.1	0.98	3.67	93.6	1.07	4.47	83.3	1.11	4.83	68.4	1.20	5.46	55.1	1.32	6.17

Table 4-3 (Continued).

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 4.0 Pt.cent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	27.9	0.62	1.29	19 9	0.66	1 68	13.9	0 73	2.20	10.3	0.79	2.73	7 9	0.85	3.28	6.3	0.92	3.78	4.9	1.06	4.21						
20	37.1	0.62	1.29	26.5	0.66	1.69	18.5	0.72	2.21	13.7	0.78	2.76	10.5	0.84	3.33	8.4	0.92	3.81	6 4	1 01	4 52	5.5	1.09	4.88			
25	46.2	0.62	1.30	33.0	0.66	1 70	23.0	0.72	2.24	17.1	0.78	2.77	13.1	0.84	3.35	10.5	0.92	3.82	8.0	1.01	4 55	6.8	1.06	5.09	5.7	1.20	5.34
30	55.3	0.62	1.30	39 5	0.66	1.70	27 6	0.72	2.23	20.4	0.77	2.82	15.7	0.84	3.36	12.5	0.91	3.92	9.5	0.99	4.71	8.2	1.07	5.03	6.7	1.15	5.71
35	64.3	0.62	1.31	46.0	0.66	1.71	32.1	0.72	2.25	23.8	0.78	2.81	18.3	0.84	3.37	14 6	0.91	3.90	11.1	0.99	4.70	9.5	1.06	5.15	7 8	1.15	5.77
40	73.3	0.62	1.31	52.4	0.66	1 71	36.6	0.72	2.25	27.1	0.77	2.83	20.8	0.83	3.42	16 6	0.90	3.96	12.7	1 00	4.68	10.8	1 04	5.24	8.9	1.14	5.81
45	82.2	0.62	1.32	58.8	0.66	1.72	41 1	0 72	2 25	30.4	0.77	2.85	23.4	0.84	3.41	18.7	0.91	3.94	14.2	0.98	4.77	12.2	1.05	5.17	10.0	1.14	5.83
50	91.1	0.62	1 32	65.2	0.66	1.72	45.6	0.72	2.26	33.7	0.77	2.86	26.0	0.84	3.40	20.7	0.90	3.97	15.8	0.99	4.74	13 5	1.05	5.24	11.1	1 14	5.85
55	99 9	0.62	1 32	71 5	0.66	1.73	50.1	0.72	2.25	37.0	0.77	2.86	28.5	0.84	3.43	22.8	0.91	3.95	17.3	0.98	4.80	14.8	1.04	5 28	12.2	1 14	5.87
60	108.7	0.62	1.32	77.8	0.66	1.73	54.5	0.72	2.25	40.3	0.77	2.87	31.0	0.83	3.45	24.8	0.90	3.97	18.9	0.99	4.77	16.1	1 04	5 32	13.3	1.14	5.88
65	117.4	0.62	1 33	84.1	0.66	1 73	58.9	0.72	2.27	43.6	0.77	2.87	33.6	0.84	3.43	26.8	0.90	3.99	20.4	0.98	4.81	17.5	1.05	5.26	14.3	1.12	6.00
70	126.1	0.62	1.33	90.3	0.66	1 74	63.3	0.72	2.27	46.9	0.77	2 86	36.1	0.84	3.44	28.8	0.90	4.01	21.9	0.98	4.85	18.8	1.04	5.29	15.4	1.12	6.00
75	134 7	0.62	1.33	96.5	0.66	1 74	67.7	0.72	2.23	50.1	0.77	2.88	38.6	0.84	3.45	30.9	0.91	3.98	23.5	0.98	4.82	20.1	1.04	5.31	16.5	1.13	5.99
80	143.3	0.62	1.34	102.7	0.66	1.74	72.1	0.72	2.23	53.3	0.77	2.89	41.1	0.84	3.46	32.9	0.91	3.99	25.0	0.98	4.84	21.4	1 04	5 33	17.6	1 13	5.98
90	160.8	0.62	1.34	115.2	0.66	1.75	80.9	0.72	2.23	59.9	0.77	2.89	46.2	0.84	3.46	36.9	0.90	4.01	28.1	0.98	4.85	24 0	1.04	5.38	19.7	1 12	6.07
100	178.2	0.62	1.34	127.7	0.66	1.75	89.7	0.72	2.29	66.4	0.77	2.90	51.2	0.84	3.47	41.0	0.91	4.00	31 2	0.98	4 85	26.7	1.04	5.35	21.9	1.12	6.05
110	195.4	0.62	1.35	140.1	0.66	1.76	98.5	0.72	2.29	72 9	0.77	2.90	56.2	0.84	3.48	45.0	0.90	4.02	34.3	0.98	4.85	29.3	1.04	5.37	24.1	1.12	6.03
120	212.6	0.62	1.35	152.5	0.66	1 76	107 2	0.72	2 30	79.4	0.77	2 90	61.2	0.84	3.49	49 0	0.90	4 03	37.3	0.98	4.88	31 9	1 04	5.40	26.2	1 12	6.09
130	229 6	0.62	1.35	164.8	0.66	1 76	115.9	0.72	2 30	85.9	0.77	2.91	66.2	0.84	3 49	53.0	0.90	4 03	40.4	0.98	4.87	34.6	1.04	5 36	28.4	1 12	6.07
140	246.6	0.62	1 36	177.0	0.66	1 77	124.5	0.72	2 30	92.3	0.77	2 91	71.2	0.84	3.49	57 0	0.90	4.04	43 4	0.98	4.90	37.2	1.04	5 38	30.5	1 12	6.10
150	263.5	0.62	1.36	189.1	0.66	1 77	133.2	0.73	2.30	98.7	0.77	2.92	76.2	0.84	3.49	61.0	0.91	4.04	46.5	0.98	4.88	39 8	1.04	5 39	32.7	1 12	6.08
160	280.3	0.62	1.36	201 2	0.66	1.78	141.7	0.73	2 31	105.1	0.77	2.92	81.1	0.84	3.50	65.0	0.91	4.04	49.5	0.98	4.90	42.4	1 04	5.40	34.8	1 12	6.11
170	296.9	0.62	1.37	213.3	0.67	1.78	150.3	0.73	2.31	111.5	0.78	2 92	86.0	0.84	3.51	68 9	0.91	4.05	52.5	0.98	4.91	45.0	1.04	5.40	36.9	1 12	6.13
180	313.5	0.62	1.37	225.3	0.67	1.78	158.8	0.73	2.32	117.8	0.78	2.93	90.9	0.84	3 52	72.9	0.91	4 05	55 6	0.98	4.90	47.6	1.04	5 40	39.1	1 12	6.11
190	330.0	0.62	1 37	237.2	0.67	1.79	167.3	0.73	2.32	124.2	0.78	2.93	95.8	0.84	3.52	76.8	0.91	4 06	58.6	0.98	4.90	50.2	1.04	5 40	41 2	1.12	6.12
200	346.4	0.62	1 37	249 1	0.67	1 79	175 7	0.73	2.32	130.5	0.78	2.93	100.7	0.84	3.52	80.7	0.91	4.07	61.6	0 98	4.91	52.7	1 04	5.43	43.3	1 12	6.14
220	380.0	0.62	1.38	273.3	0.67	1 79	192.9	0.73	2 33	143.3	0.78	2.93	110.6	0.84	3.53	88.7	0.91	4.07	67.6	0.98	4.93	57.9	1.04	5.44	47.6	1 12	6.14
240	413 3	0.62	1.38	297.4	0.67	1.80	209.9	0.73	2.33	156.0	0.78	2.94	120.4	0.84	3.53	96.6	0.91	4.07	73.7	0.98	4.93	63.1	1.04	5.44	51.9	1.12	6.14
260	446.5	0.62	1.39	321.4	0.67	1.80	227.0	0.73	2 33	168.7	0.78	2.94	130.2	0.84	3.54	104.5	0.91	4.08	79.7	0.98	4.94	68.3	1.04	5 44	56.2	1.12	6.13
280	479.5	0.62	1 39	345.3	0.67	1.80	243 9	0.73	2.34	181.3	0.78	2.95	140.0	0.84	3.54	112.3	0.91	4.09	85.8	0.99	4.93	73.5	1.04	5.44	60.4	1 12	6.15
300	512 3	0.62	1.39	369.0	0.67	1.81	260.8	0.73	2.34	193.9	0.78	2 95	149.8	0.84	3.55	120.2	0.91	4.09	91.8	0 99	4.94	78.6	1.04	5.46	64.7	1.12	6.14

Table 4-3 (Continued).

V_1 for RETARDANCE "D" Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 5.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	29.3	0.57	1.33	21.1	0.60	1.74	15.0	0.66	2.23	12.2	0.70	2.58	9.0	0.75	3.25	7.2	0.83	3.70	5.8	0.93	4.09	4.6	0.99	4.81			
20	39.0	0.57	1.33	28.1	0.61	1.74	19.9	0.66	2.26	16.2	0.70	2.62	12.0	0.75	3.26	9.5	0.81	3.84	7.6	0.89	4.35	6.1	0.97	4.95	5.3	1.06	5.21
25	48.6	0.57	1.34	35.1	0.61	1.73	24.8	0.66	2.28	20.3	0.70	2.59	15.0	0.75	3.27	11.9	0.81	3.82	9.5	0.89	4.37	7.6	0.96	5.03	6.5	1.02	5.56
30	58.1	0.57	1.34	42.0	0.61	1.74	29.7	0.66	2.28	24.3	0.70	2.61	18.0	0.76	3.26	14.2	0.80	3.89	11.3	0.87	4.49	9.1	0.96	5.08	7.8	1.01	5.59
35	67.6	0.57	1.35	48.8	0.61	1.75	34.6	0.66	2.28	28.2	0.70	2.64	20.9	0.75	3.30	16.6	0.81	3.86	13.2	0.88	4.47	10.5	0.94	5.26	9.1	1.01	5.60
40	77.0	0.57	1.35	55.7	0.61	1.75	39.5	0.66	2.28	32.2	0.70	2.64	23.9	0.75	3.29	18.9	0.80	3.90	15.1	0.88	4.46	12.0	0.94	5.26	10.3	0.99	5.77
45	86.4	0.57	1.35	62.5	0.61	1.75	44.3	0.66	2.29	36.1	0.70	2.65	26.8	0.75	3.31	21.3	0.81	3.87	16.9	0.87	4.52	13.5	0.94	5.25	11.6	1.00	5.75
50	95.7	0.57	1.36	69.2	0.61	1.76	49.1	0.66	2.30	40.1	0.70	2.64	29.7	0.75	3.32	23.6	0.81	3.89	18.8	0.88	4.50	15.0	0.94	5.25	12.9	1.00	5.73
55	105.0	0.57	1.36	75.9	0.61	1.77	53.9	0.66	2.30	44.0	0.70	2.65	32.6	0.75	3.33	25.9	0.81	3.90	20.6	0.87	4.54	16.5	0.94	5.24	14.1	0.99	5.84
60	114.2	0.57	1.36	82.6	0.61	1.77	58.7	0.66	2.30	47.9	0.70	2.66	35.5	0.75	3.34	28.2	0.81	3.92	22.4	0.87	4.57	17.9	0.93	5.32	15.4	0.99	5.81
65	123.4	0.57	1.36	89.3	0.61	1.77	63.4	0.66	2.31	51.8	0.70	2.66	38.4	0.75	3.34	30.5	0.81	3.92	24.3	0.87	4.54	19.4	0.94	5.30	16.7	1.00	5.78
70	132.4	0.57	1.37	95.9	0.61	1.77	68.2	0.66	2.31	55.6	0.70	2.67	41.3	0.75	3.34	32.8	0.81	3.93	26.1	0.87	4.56	20.8	0.93	5.36	17.9	0.99	5.85
75	141.5	0.57	1.37	102.4	0.61	1.78	72.9	0.66	2.31	59.4	0.70	2.68	44.1	0.75	3.36	35.1	0.81	3.93	27.9	0.87	4.58	22.3	0.93	5.34	19.2	1.00	5.82
80	150.5	0.57	1.37	109.0	0.61	1.78	77.5	0.66	2.32	63.3	0.70	2.68	47.0	0.75	3.36	37.4	0.81	3.92	29.7	0.87	4.60	23.8	0.94	5.32	20.4	0.99	5.88
90	168.8	0.57	1.38	122.3	0.61	1.79	87.0	0.66	2.33	71.0	0.70	2.69	52.8	0.75	3.36	42.0	0.81	3.93	33.4	0.87	4.59	26.7	0.94	5.35	22.9	0.99	5.91
100	187.0	0.57	1.38	135.5	0.61	1.79	96.5	0.66	2.33	78.7	0.70	2.70	58.5	0.75	3.37	46.5	0.81	3.96	37.0	0.87	4.62	29.6	0.93	5.38	25.5	0.99	5.86
110	205.1	0.57	1.38	148.7	0.61	1.79	105.9	0.66	2.33	86.4	0.70	2.70	64.3	0.75	3.37	51.1	0.81	3.96	40.7	0.87	4.61	32.5	0.93	5.39	28.0	0.99	5.88
120	223.1	0.57	1.39	161.8	0.61	1.80	115.3	0.66	2.33	94.1	0.70	2.70	70.0	0.75	3.38	55.7	0.81	3.96	44.3	0.87	4.62	35.4	0.93	5.41	30.5	0.99	5.89
130	240.9	0.57	1.39	174.8	0.61	1.80	124.6	0.66	2.34	101.7	0.70	2.71	75.7	0.76	3.38	60.2	0.81	3.97	47.9	0.87	4.64	38.3	0.93	5.41	33.0	0.99	5.90
140	258.7	0.57	1.40	187.7	0.61	1.81	133.9	0.66	2.34	109.3	0.70	2.71	81.3	0.75	3.39	64.7	0.81	3.98	51.5	0.87	4.64	41.2	0.93	5.42	35.5	0.99	5.91
150	276.4	0.58	1.40	200.6	0.61	1.81	143.1	0.66	2.35	116.8	0.70	2.72	87.0	0.76	3.39	69.3	0.81	3.97	55.1	0.87	4.65	44.1	0.93	5.42	37.9	0.99	5.96
160	293.9	0.58	1.40	213.4	0.61	1.81	152.3	0.66	2.35	124.3	0.70	2.72	92.6	0.76	3.40	73.7	0.81	3.99	58.7	0.87	4.65	47.0	0.94	5.42	40.4	0.99	5.95
170	311.4	0.58	1.40	226.1	0.61	1.82	161.5	0.66	2.35	131.8	0.70	2.73	98.2	0.76	3.41	78.2	0.81	3.99	62.3	0.87	4.65	49.9	0.94	5.41	42.9	0.99	5.95
180	328.7	0.58	1.41	238.8	0.61	1.82	170.6	0.66	2.36	139.2	0.70	2.73	103.8	0.76	3.41	82.7	0.81	3.99	65.9	0.87	4.65	52.7	0.93	5.44	45.4	0.99	5.94
190	346.0	0.58	1.41	251.4	0.61	1.83	179.7	0.67	2.36	146.6	0.70	2.74	109.4	0.76	3.41	87.1	0.81	4.00	69.4	0.87	4.67	55.6	0.94	5.43	47.8	0.99	5.97
200	363.1	0.58	1.42	263.9	0.61	1.83	188.7	0.67	2.37	154.0	0.70	2.74	114.9	0.76	3.42	91.6	0.81	4.00	73.0	0.87	4.66	58.4	0.94	5.45	50.3	0.99	5.96
220	398.3	0.58	1.42	289.6	0.62	1.83	207.1	0.67	2.37	169.0	0.70	2.75	126.1	0.76	3.43	100.6	0.81	4.00	80.1	0.87	4.68	64.2	0.94	5.45	55.2	0.99	5.99
240	433.2	0.58	1.42	315.0	0.62	1.84	225.4	0.67	2.37	184.0	0.70	2.75	137.4	0.76	3.43	109.5	0.81	4.01	87.3	0.87	4.68	69.9	0.94	5.46	60.2	0.99	5.98
260	467.9	0.58	1.43	340.4	0.62	1.84	243.7	0.67	2.38	198.9	0.70	2.76	148.5	0.76	3.44	118.5	0.81	4.01	94.4	0.87	4.69	75.6	0.94	5.47	65.1	0.99	5.99
280	502.5	0.58	1.43	365.6	0.62	1.84	261.8	0.67	2.38	213.7	0.70	2.76	159.7	0.76	3.44	127.4	0.81	4.02	101.5	0.87	4.70	81.4	0.94	5.46	70.0	0.99	6.01
300	536.7	0.58	1.43	390.7	0.62	1.85	279.9	0.67	2.38	228.5	0.71	2.77	170.7	0.76	3.45	136.2	0.81	4.03	108.6	0.87	4.70	87.0	0.94	5.48	74.9	0.99	6.01

Table 4-3 (Continued).

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 6.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	34.6	0.53	1.22	22.6	0.57	1.72	16.6	0.61	2.20	12.6	0.65	2.68	10.0	0.70	3.15	8.1	0.76	3.59	6.6	0.82	4.05	5.3	0.90	4.61	4.3	0.98	5.19
20	46.0	0.53	1.22	30.0	0.57	1.73	22.1	0.61	2.20	16.8	0.66	2.68	13.2	0.69	3.25	10.7	0.74	3.71	8.7	0.80	4.22	7.0	0.88	4.79	5.7	0.96	5 36
25	57.2	0.52	1.23	37.4	0.57	1 74	27.6	0.61	2.20	21.0	0.66	2.68	16.5	0.69	3.25	13.3	0.73	3.78	10.8	0.79	4.32	8.7	0.86	4.90	7.0	0.92	5.69
30	68.5	0.53	1.23	44.7	0.57	1.75	33.0	0.61	2.22	25.1	0.66	2.70	19.8	0.69	3.24	16.0	0.74	3.75	13.0	0.80	4.29	10.4	0.86	4.97	8.4	0.92	5.71
35	79.6	0.53	1.24	52.0	0.57	1.76	38.4	0.61	2.22	29.2	0.65	2.71	23.0	0.69	3.28	18.6	0.74	3.78	15.1	0.79	4.34	12.1	0.85	5.01	9.8	0.92	5.72
40	90.6	0.52	1.24	59.3	0.57	1.76	43.8	0.61	2.22	33.3	0.65	2 72	26.3	0.69	3.26	21.2	0.74	3.80	17.2	0.79	4.37	13.8	0.85	5.04	11.2	0.92	5.72
45	101.6	0.53	1 25	66.5	0.57	1.76	49.1	0.61	2.24	37.4	0.66	2.72	29.5	0.69	3.28	23.8	0.73	3.81	19.4	0.79	4.33	15.5	0.85	5.05	12.5	0.91	5.85
50	112.5	0.53	1.25	73.6	0.57	1.77	54.4	0.61	2.24	41.5	0.66	2 72	32.7	0.69	3.29	26.4	0.74	3.82	21.5	0.79	4.35	17.2	0.85	5.06	13.9	0.91	5.83
55	123.3	0.53	1.25	80.8	0.57	1.77	59.7	0.61	2.25	45.5	0.66	2.73	35.9	0.69	3.29	29.0	0.74	3.82	23.6	0.79	4.37	18.8	0.84	5.15	15.3	0.92	5.82
60	134.1	0.53	1.26	87.8	0.57	1.78	65.0	0.61	2.25	49.5	0.66	2.74	39.1	0.69	3.30	31.6	0.74	3.82	25.7	0.79	4.38	20.5	0.84	5.14	16.6	0.91	5.90
65	144.7	0.53	1.26	94.9	0.57	1.78	70.2	0.61	2.26	53.5	0.66	2.75	42.2	0.69	3.32	34.1	0.73	3.85	27.8	0.79	4.38	22.2	0.85	5.14	18.0	0.91	5.87
70	155.3	0.53	1.27	101.9	0.57	1.79	75.4	0.61	2 26	57.5	0.66	2 75	45.4	0.69	3.31	36.7	0.74	3.84	29.9	0.79	4.39	23.9	0.85	5.13	19.3	0.91	5 94
75	165.8	0.53	1.27	108.8	0.57	1.80	80.6	0.61	2.26	61.5	0.66	2.75	48.5	0.69	3.33	39.2	0.73	3.86	31.9	0.79	4.43	25.5	0.84	5.18	20.7	0.91	5.91
80	176.3	0.53	1.27	115.7	0.57	1.80	85.8	0.61	2.27	65.4	0.66	2.76	51.7	0.69	3.32	41.8	0.74	3.85	34.0	0.79	4.42	27.2	0.85	5.16	22.0	0.91	5.96
90	197.6	0.53	1.28	129.8	0.57	1.80	96.2	0.61	2.28	73.4	0.66	2.77	58.0	0.69	3.33	46.9	0.74	3.87	38.2	0.79	4.43	30.5	0.84	5.20	24.8	0.91	5.91
100	218.8	0.53	1.28	143.8	0.57	1.81	106.6	0.61	2.28	81.4	0.66	2.77	64.3	0.69	3.34	52.0	0.74	3.88	42.4	0.79	4.42	33.9	0.85	5.18	27.5	0.91	5.93
110	239.9	0.53	1 28	157.7	0.57	1.81	117.0	0.61	2.28	89.3	0.66	2.78	70.6	0.69	3.35	57.1	0.74	3.88	46.5	0.79	4.45	37.2	0.84	5.20	30.2	0.91	5.95
120	260.8	0.53	1.29	171.5	0.57	1.82	127.3	0.61	2.29	97.2	0.66	2.79	76.9	0.69	3.35	62.2	0.74	3.89	50.7	0.79	4.44	40.5	0.84	5.22	32.9	0.91	5 96
130	281.5	0.53	1.29	185.3	0.57	1.82	137.6	0.61	2.29	105.1	0 66	2 79	83.1	0.69	3.36	67 2	0.74	3 90	54.8	0.79	4.46	43.8	0.84	5 23	35.6	0.91	5.96
140	302.1	0.53	1 30	199.0	0.57	1 83	147.8	0.61	2.30	112.9	0.66	2.80	89 3	0.69	3.36	72 3	0.74	3.90	58.9	0.79	4.46	47.1	0.84	5 24	38.3	0.91	5.97
150	322.6	0.53	1.30	212.6	0.57	1.83	157.9	0.61	2.30	120 7	0.66	2.80	95.5	0.69	3.37	77.3	0.74	3.91	63.0	0.79	4.47	50.4	0 84	5.24	40.9	0.91	6.01
160	342.9	0.53	1.30	226.1	0.57	1.84	168.0	0.61	2.31	128.5	0.66	2.80	101.7	0.69	3 37	82.3	0.74	3.91	67.1	0.79	4.47	53 7	0.85	5.24	43.6	0.91	6.00
170	363.1	0.53	1.31	239 6	0 57	1.84	178 0	0.61	2.32	136.2	0.66	2.81	107 8	0.69	3.37	87.3	0.74	3.91	71.2	0.79	4.47	56.9	0.84	5.27	46.3	0.91	5.99
180	383.1	0.53	1.31	253.0	0.57	1.84	188.0	0.61	2.32	143.9	0.66	2.81	113.9	0.69	3.38	92 2	0.74	3 93	75.2	0.79	4.49	60.2	0.85	5.26	48.9	0.91	6.02
190	403.0	0.53	1 32	266.3	0.57	1.85	197.9	0.61	2.33	151 5	0.66	2.82	120.0	0.70	3 38	97.1	0.74	3.94	79 3	0.79	4.49	63.4	0.84	5.28	51 6	0.91	6.01
200	422.7	0.53	1 32	279.5	0.57	1 85	207.8	0.61	2.33	159.1	0.66	2.82	126.1	0.70	3.39	102.1	0.74	3 93	83.3	0.79	4.50	66.7	0.85	5.27	54.2	0.91	6.03
220	463.4	0.53	1.32	306.6	0.57	1.86	228.0	0 61	2.33	174.6	0.66	2.83	138.4	0.70	3.39	112.0	0.74	3.95	91.5	0.79	4.50	73.2	0.85	5.29	59.6	0.91	6.02
240	503.8	0.53	1.33	333.6	0.57	1.86	248.1	0.61	2.34	190.1	0.66	2.83	150.7	0.70	3.40	122.0	0.74	3.95	99.7	0.80	4.50	79.8	0.85	5.28	64.9	0.91	6.04
260	543.8	0.53	1.33	360.4	0.57	1.86	268.1	0.61	2.34	205.4	0.66	2.84	162.9	0 70	3.40	131 9	0.74	3.96	107.8	0.80	4.51	86.3	0.85	5.29	70.2	0.91	6.05
280	583.6	0.53	1.34	387.0	0.57	1.87	287.9	0.61	2.35	220.7	0.66	2.85	175.1	0.70	3.41	141.8	0.74	3.96	115.9	0.80	4.51	92.8	0.85	5.30	75.5	0.91	6.05
300	623.2	0.53	1.34	413.5	0.58	1.87	307.7	0.61	2.35	235.9	0.66	2.85	187.2	0.70	3.41	151.6	0.74	3.97	123.9	0.80	4.53	99.3	0.85	5.30	80.8	0.91	6.06

Table 4-3 (Continued).

V_1 for RETARDANCE "D" Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 8.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	37.0	0.47	1.26	26.6	0.51	1.65	18.7	0.54	2.19	15.3	0.57	2.54	11.7	0.61	3.08	9.4	0.65	3.61	7.9	0.70	3.99	6.4	0.74	4.62	5.3	0.80	5.18
20	49.2	0.47	1.26	35.3	0.50	1.66	24.9	0.54	2.19	20.4	0.57	2.54	15.6	0.61	3.08	12.5	0.65	3.65	10.4	0.68	4.17	8.5	0.74	4.70	7.1	0.80	5.16
25	61.2	0.47	1.27	44.0	0.50	1.67	31.0	0.54	2.21	25.4	0.57	2.56	19.4	0.61	3.12	15.6	0.65	3.67	13.0	0.68	4.17	10.6	0.73	4.75	8.8	0.79	5.32
30	73.2	0.47	1.28	52.6	0.50	1.67	37.2	0.54	2.19	30.4	0.57	2.57	23.3	0.61	3.10	18.7	0.65	3.67	15.6	0.68	4.17	12.7	0.73	4.77	10.5	0.78	5.41
35	85.1	0.47	1.28	61.2	0.50	1.68	43.2	0.54	2.21	35.3	0.57	2.59	27.1	0.61	3.12	21.7	0.64	3.72	18.1	0.68	4.23	14.8	0.73	4.78	12.2	0.77	5.48
40	96.9	0.47	1.28	69.7	0.50	1.68	49.3	0.54	2.21	40.3	0.57	2.59	30.9	0.61	3.13	24.8	0.64	3.71	20.7	0.68	4.20	16.9	0.73	4.78	13.9	0.77	5.53
45	108.6	0.47	1.29	78.2	0.51	1.68	55.3	0.54	2.22	45.2	0.57	2.60	34.6	0.61	3.16	27.8	0.64	3.73	23.2	0.68	4.24	19.0	0.73	4.78	15.7	0.78	5.45
50	120.2	0.48	1.29	86.5	0.50	1.69	61.2	0.54	2.23	50.0	0.57	2.62	38.4	0.61	3.15	30.9	0.65	3.71	25.8	0.68	4.21	21.0	0.73	4.84	17.4	0.78	5.48
55	131.8	0.48	1.30	94.9	0.51	1.70	67.1	0.54	2.24	54.9	0.57	2.62	42.1	0.61	3.17	33.9	0.65	3.73	28.3	0.68	4.23	23.1	0.73	4.83	19.1	0.78	5.50
60	143.2	0.48	1.30	103.1	0.51	1.70	73.0	0.54	2.24	59.7	0.57	2.62	45.9	0.61	3.16	36.9	0.65	3.73	30.8	0.68	4.24	25.1	0.73	4.87	20.8	0.78	5.51
65	154.6	0.48	1.30	111.4	0.51	1.71	78.9	0.54	2.24	64.5	0.57	2.63	49.6	0.61	3.16	39.9	0.65	3.74	33.3	0.68	4.25	27.2	0.73	4.85	22.5	0.78	5.52
70	165.9	0.48	1.31	119.5	0.51	1.71	84.7	0.54	2.25	69.3	0.57	2.63	53.2	0.61	3.19	42.8	0.64	3.76	35.8	0.68	4.26	29.2	0.73	4.88	24.1	0.77	5.59
75	177.1	0.48	1.31	127.6	0.51	1.72	90.5	0.54	2.25	74.1	0.57	2.63	56.9	0.61	3.19	45.8	0.65	3.76	38.2	0.68	4.29	31.2	0.73	4.90	25.8	0.77	5.59
80	188.2	0.48	1.32	135.6	0.51	1.72	96.2	0.54	2.26	78.8	0.57	2.64	60.5	0.61	3.20	48.7	0.64	3.78	40.7	0.68	4.29	33.3	0.73	4.87	27.5	0.77	5.58
90	210.9	0.48	1.32	152.1	0.51	1.73	108.0	0.55	2.26	88.4	0.57	2.65	67.9	0.61	3.21	54.7	0.65	3.78	45.7	0.68	4.29	37.4	0.73	4.88	30.9	0.77	5.59
100	233.5	0.48	1.32	168.4	0.51	1.73	119.6	0.55	2.27	98.0	0.57	2.65	75.3	0.61	3.21	60.7	0.65	3.78	50.6	0.68	4.32	41.4	0.73	4.92	34.2	0.77	5.64
110	255.9	0.48	1.33	184.6	0.51	1.74	131.2	0.55	2.28	107.5	0.57	2.66	82.6	0.61	3.22	66.6	0.65	3.79	55.6	0.68	4.32	45.5	0.73	4.91	37.6	0.77	5.63
120	278.1	0.48	1.33	200.7	0.51	1.74	142.7	0.55	2.28	116.9	0.57	2.67	89.9	0.61	3.22	72.5	0.65	3.79	60.5	0.68	4.33	49.5	0.73	4.93	40.9	0.77	5.66
130	300.2	0.48	1.34	216.6	0.51	1.75	154.1	0.55	2.29	126.4	0.57	2.67	97.1	0.61	3.24	78.3	0.65	3.81	65.4	0.68	4.34	53.6	0.73	4.92	44.3	0.77	5.64
140	322.1	0.48	1.34	232.5	0.51	1.76	165.5	0.55	2.29	135.7	0.57	2.67	104.4	0.62	3.23	84.2	0.65	3.81	70.3	0.68	4.34	57.6	0.73	4.93	47.6	0.77	5.66
150	343.9	0.48	1.34	248.3	0.51	1.76	176.8	0.55	2.30	145.0	0.57	2.68	111.5	0.61	3.25	90.0	0.65	3.82	75.2	0.68	4.35	61.6	0.73	4.94	50.9	0.77	5.67
160	365.5	0.48	1.35	264.0	0.51	1.76	188.1	0.55	2.30	154.3	0.57	2.68	118.7	0.62	3.25	95.8	0.65	3.82	80.0	0.68	4.36	65.6	0.73	4.94	54.2	0.77	5.68
170	386.9	0.48	1.35	279.6	0.51	1.77	199.3	0.55	2.31	163.5	0.57	2.69	125.8	0.62	3.26	101.6	0.65	3.82	84.8	0.68	4.37	69.5	0.73	4.97	57.5	0.77	5.69
180	408.2	0.48	1.36	295.1	0.51	1.77	210.4	0.55	2.31	172.7	0.57	2.69	132.8	0.62	3.27	107.3	0.65	3.84	89.7	0.68	4.36	73.5	0.73	4.96	60.8	0.77	5.69
190	429.3	0.48	1.36	310.5	0.51	1.78	221.4	0.55	2.32	181.8	0.57	2.70	139.9	0.62	3.27	113.0	0.65	3.84	94.4	0.68	4.38	77.4	0.73	4.98	64.0	0.77	5.71
200	450.2	0.48	1.36	325.7	0.51	1.78	232.4	0.55	2.32	190.8	0.57	2.71	146.9	0.62	3.28	118.7	0.65	3.85	99.2	0.68	4.39	81.4	0.73	4.97	67.3	0.77	5.71
220	493.4	0.48	1.37	357.1	0.51	1.79	254.9	0.55	2.33	209.4	0.58	2.71	161.1	0.62	3.29	130.3	0.65	3.85	108.9	0.68	4.39	89.3	0.73	4.99	73.9	0.77	5.72
240	536.2	0.48	1.37	388.3	0.51	1.79	277.3	0.55	2.34	227.8	0.58	2.71	175.4	0.62	3.29	141.8	0.65	3.86	118.6	0.68	4.40	97.3	0.74	4.99	80.5	0.77	5.72
260	578.8	0.48	1.38	419.3	0.51	1.80	299.5	0.55	2.34	246.2	0.58	2.72	189.5	0.62	3.30	153.3	0.65	3.87	128.2	0.68	4.40	105.2	0.74	5.00	87.0	0.77	5.74
280	621.1	0.48	1.38	450.1	0.51	1.80	321.6	0.55	2.35	264.4	0.58	2.72	203.6	0.62	3.31	164.8	0.65	3.87	137.8	0.68	4.41	113.1	0.74	5.00	93.5	0.77	5.76
300	663.1	0.48	1.39	480.7	0.51	1.81	343.6	0.55	2.35	282.6	0.58	2.73	217.6	0.62	3.31	176.1	0.65	3.88	147.4	0.69	4.41	120.9	0.74	5.02	100.1	0.78	5.75

Table 4-3 (Continued).

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 10.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	45.2	0.43	1.14	32.5	0.45	1.50	22.9	0.49	1.98	16.6	0.52	2.56	13.4	0.55	2.99	10.7	0.58	3.55	9.0	0.61	3.99	7.4	0.65	4.57	6.2	0.70	5.08
20	60.1	0.43	1.14	43.2	0.45	1.50	30.4	0.49	2.00	22.1	0.52	2.56	17.8	0.55	3.02	14.3	0.59	3.52	12.0	0.61	4.00	9.9	0.65	4.55	8.3	0.70	5.06
25	74.8	0.43	1.15	53.8	0.45	1.51	37.9	0.49	2.00	27.5	0.52	2.59	22.3	0.55	2.99	17.8	0.58	3.56	14.9	0.61	4.08	12.3	0.65	4.63	10.3	0.69	5.18
30	89.3	0.43	1.15	64.2	0.45	1 52	45.3	0.49	2.01	33.0	0.52	2.58	26.6	0.55	3.03	21 3	0.58	3.58	17.9	0.61	4.05	14.7	0.64	4.68	12.4	0.70	5.13
35	103.7	0.43	1.16	74 6	0.45	1.53	52.6	0.48	2.03	38.3	0.52	2.60	31.0	0.55	3.02	24.8	0.58	3.59	20.8	0.61	4.09	17.2	0.65	4.63	14.4	0.69	5.19
40	118.0	0.43	1.16	85.0	0.46	1.53	59.9	0.48	2.04	43.7	0.52	2.60	35.3	0.55	3.04	28.3	0.58	3.59	23.8	0.61	4.06	19.6	0.65	4.66	16.4	0.69	5.24
45	132.2	0.43	1.17	95.2	0.45	1 53	67.2	0.49	2.04	49.0	0.52	2.61	39 6	0.55	3.05	31.7	0.58	3.62	26.7	0.61	4.08	22.0	0.65	4.68	18.4	0.69	5.27
50	146.3	0.43	1.17	105.3	0.45	1.54	74.4	0.49	2.04	54.3	0.52	2.61	43.9	0.55	3.05	35.2	0.58	3.61	29.6	0.61	4.09	24.4	0.65	4.68	20.4	0.69	5.28
55	160.2	0.43	1.17	115.4	0.46	1 55	81.5	0.49	2.06	59.5	0.52	2.63	48.2	0.55	3.05	38.6	0.58	3.62	32.4	0.61	4.13	26.7	0.64	4.74	22.4	0.69	5.29
60	174.0	0.43	1.18	125.3	0.46	1.55	88.6	0.49	2.06	64.7	0.52	2.63	52.4	0.55	3.07	42.0	0.58	3.63	35.3	0.61	4.12	29.1	0.65	4.73	24.4	0.69	5.30
65	187.6	0.43	1.18	135.2	0.46	1.56	95.6	0.49	2.07	69.9	0.52	2.64	56.6	0.55	3.08	45.4	0.58	3.64	38.2	0.61	4.12	31.5	0.65	4.72	26.4	0.69	5.30
70	201.2	0.43	1.19	145.0	0.46	1.57	102.6	0.49	2.08	75.1	0.52	2.64	60.8	0.55	3.08	48.7	0.58	3.66	41.0	0.61	4.14	33.8	0.65	4.75	28.4	0.69	5.29
75	214.6	0.43	1.19	154.7	0.46	1.57	109.6	0.49	2.08	80.2	0.52	2.65	65.0	0.55	3.08	52.1	0.58	3.66	43.8	0.61	4.15	36.2	0.65	4.74	30.3	0.69	5.34
80	227.9	0.43	1.20	164.3	0.46	1.58	116.4	0.49	2.09	85.3	0.52	2.65	69.1	0.55	3.09	55.4	0.58	3.67	46.6	0.61	4.16	38.5	0.65	4.76	32.3	0.69	5.33
90	255.2	0.43	1.20	184.1	0.46	1.58	130.5	0.49	2.10	95.6	0.52	2.67	77.5	0.55	3.11	62.1	0.58	3.69	52.3	0.61	4.17	43.2	0.65	4.78	36.3	0.69	5.33
100	282.4	0.43	1.20	203.7	0.46	1.59	144.5	0.49	2.10	105.9	0.52	2.67	85.9	0.56	3.11	68.8	0.58	3.70	58.0	0.61	4.18	47.9	0.65	4.78	40.2	0.69	5.36
110	309.2	0.43	1 21	223.2	0.46	1.60	158.4	0.49	2.11	116.2	0.52	2.68	94.3	0.56	3.11	75.5	0.58	3.71	63.7	0.61	4.18	52.6	0.65	4.79	44.2	0.69	5.34
120	335.9	0.43	1.21	242.4	0.46	1.60	172.2	0.49	2.12	126.4	0.52	2.68	102.5	0.56	3.12	82.2	0.58	3.71	69.3	0.61	4.19	57.3	0.65	4.79	48.1	0.69	5.36
130	362.3	0.43	1.22	261.6	0.46	1.61	185.9	0.49	2.12	136.5	0.52	2.69	110.8	0 56	3.13	88.8	0.58	3.72	74.9	0.61	4.20	61.9	0.65	4.81	52.0	0.69	5.37
140	388.4	0.44	1.22	280.5	0.46	1.61	199 5	0.49	2.13	146.5	0.52	2.70	119.0	0.56	3.13	95.4	0.58	3.73	80.5	0.61	4.20	66.5	0.65	4.82	55.9	0.69	5.38
150	414.4	0.44	1 23	299.3	0.46	1.62	213.0	0.49	2.13	156.5	0.52	2.71	127.1	0.56	3.14	101.9	0.58	3.74	86.0	0.61	4.22	71.1	0.65	4.83	59.7	0.69	5.41
160	440.1	0.44	1.23	318.1	0.46	1 62	226.5	0.49	2.14	166.4	0.53	2.71	135.2	0.56	3 15	108.4	0.58	3.75	91.6	0.62	4.21	75.7	0.65	4.83	63.6	0.69	5.41
170	465.5	0.44	1.24	336.7	0.46	1.63	239.8	0.49	2.14	176.3	0.53	2.72	143.3	0.56	3.15	114.9	0.58	3.76	97.1	0.62	4.22	80.3	0.65	4.83	67.4	0.69	5.42
180	490.8	0.44	1.24	355.1	0.46	1.63	253.1	0.49	2.15	186.1	0.53	2.73	151.3	0.56	3.16	121 3	0.58	3.77	102.5	0.62	4.24	84.9	0.65	4.83	71.3	0.69	5.42
190	515.7	0.44	1.25	373.5	0.46	1.64	266.3	0.49	2.15	195.9	0.53	2.73	159.3	0.56	3.17	127.7	0.58	3.78	108.0	0.62	4.24	89.4	0.65	4.84	75.1	0.69	5.43
200	540.5	0.44	1.25	391.6	0.46	1.64	279.4	0.49	2.16	205.6	0.53	2.74	167.2	0.56	3.17	134.1	0.58	3.79	113.4	0.62	4.25	93.9	0.65	4.85	78.9	0.69	5.43
220	592.0	0.44	1 26	429.2	0.46	1.65	306.3	0.49	2.17	225.4	0.53	2.75	183.5	0 56	3.18	147.1	0.58	3.80	124.4	0.62	4.26	103.1	0.65	4.85	86.6	0.69	5.45
240	643.0	0.44	1.26	466.4	0.46	1 65	333.1	0.49	2.17	245.2	0.53	2.75	199.6	0.56	3.19	160.0	0.58	3.81	135.4	0.62	4.27	112.2	0.65	4.87	94.3	0.69	5.45
260	693.6	0.44	1.27	503 4	0.46	1 66	359.6	0.49	2.18	264.8	0.53	2.76	215.6	0.56	3.19	172.9	0.58	3.82	146.4	0.62	4.27	121.3	0.65	4.87	101.9	0.69	5.47
280	743.7	0.44	1.27	540.0	0.46	1.66	386.0	0.49	2.18	284.4	0.53	2.77	231 6	0.56	3.20	185 8	0.59	3.82	157.3	0.62	4.28	130.4	0.65	4.88	109.6	0.69	5.47
300	793.4	0.44	1.28	576.4	0.46	1.67	412.3	0.49	2.19	303.8	0.53	2.77	247 5	0.56	3.21	198.6	0.59	3.83	168.1	0.62	4.29	139.4	0.65	4.89	117.2	0.69	5.48

The design conditions normally accepted in Alabama are that initial vegetative conditions correspond to retardance "D" and that conditions will fluctuate between "D" and "C". Table 4-3 incorporates this assumption. Freeboard of 0.5 feet is normally added to the required depths determined from the table.

The waterway design charts are for a parabolic shape. It would add conservatism to construct the waterway with a trapezoidal shape. It may be assumed with reasonable accuracy that the shape will deteriorate to parabolic.

The bottom width of a waterway should be limited to approximately 100 feet. This helps limit meander during small flows. A minimum width of about 40 feet is needed for farm equipment crossing, but this is not always an essential feature in a gully control measure.

Suggested Addition to SCS Procedure

The above procedure does not necessarily provide a waterway that will weather conditions immediately after construction. Bare soil velocities in waterways need to be kept below 3.0 fps in erosion-resistant soils such as CH, MH, CL and the more plastic SC soils. In less resistant soils, the velocity over bare soil should not exceed 2.0 fps (2, Table 2) except in the case of fine sands of the SP, SW groups and the ML, SM and SC soils with minor cohesion. These latter materials must be protected immediately with sod or other resistant media.

The storms a new waterway must usually weather are the small, commonplace rains. Therefore, if the waterway can weather the 1-year, 24-hour storm without velocities that are erosive to the bare soil, it should have a good chance of developing vegetation and surviving.

Figures 4-2 through 4-5 may be used to check and modify the waterway size established for "aged" conditions to make certain it is satisfactory for new or "as-built" conditions, observing the following steps:

(1) Determine the peak rate of discharge from Figures 3-2 through 3-22 using the 1-year, 24-hour storm from Table 3-1.

(2) Select the appropriate permissible bare soil velocity.

(3) Determine the design gradient for the waterway.

(4) Pass a line through values for design gradient (slope) and allowable velocity on Figure 4-2 to locate a pivot point.

(5) Pass a line through the pivot point and a Manning's "n" = 0.04 and determine the corresponding hydraulic radius.

(6) Divide the peak rate of discharge by the permissible velocity to determine the required flow area.

(7) Intersect hydraulic radius and flow area values in Figure 4-3 and determine the required top width, t.

(8) Still on Figure 4-3, read the depth, d, corresponding to the hydraulic radius from the righthand portion of the figure.

(9) Using Figure 4-4, pass a line through center depth and top width (determined in previous two steps) and locate a pivot point. All straight lines through the pivot point and points on the "d" and "t" curves define points on the same parabola.

(10) Pass a line through the pivot point and the waterway depth determined using the 10-year, 24-hour storm (not the value from step 8). Read the "t" where this line passes through it. If the width indicated is greater than the width of the waterway required for the 10-year, 24-hour storm, the original trial design needs to be modified to prevent scour of bare soil. The modification is by trial, as follows.

(11) Assume a value for "d" somewhere between the two values determined for the 1 and 10-year storms, and select a corresponding "t" from Figure 4-4 (using the pivot point already established).

(12) Enter Figure 4-3 with "d" and "t" and determine A and R,

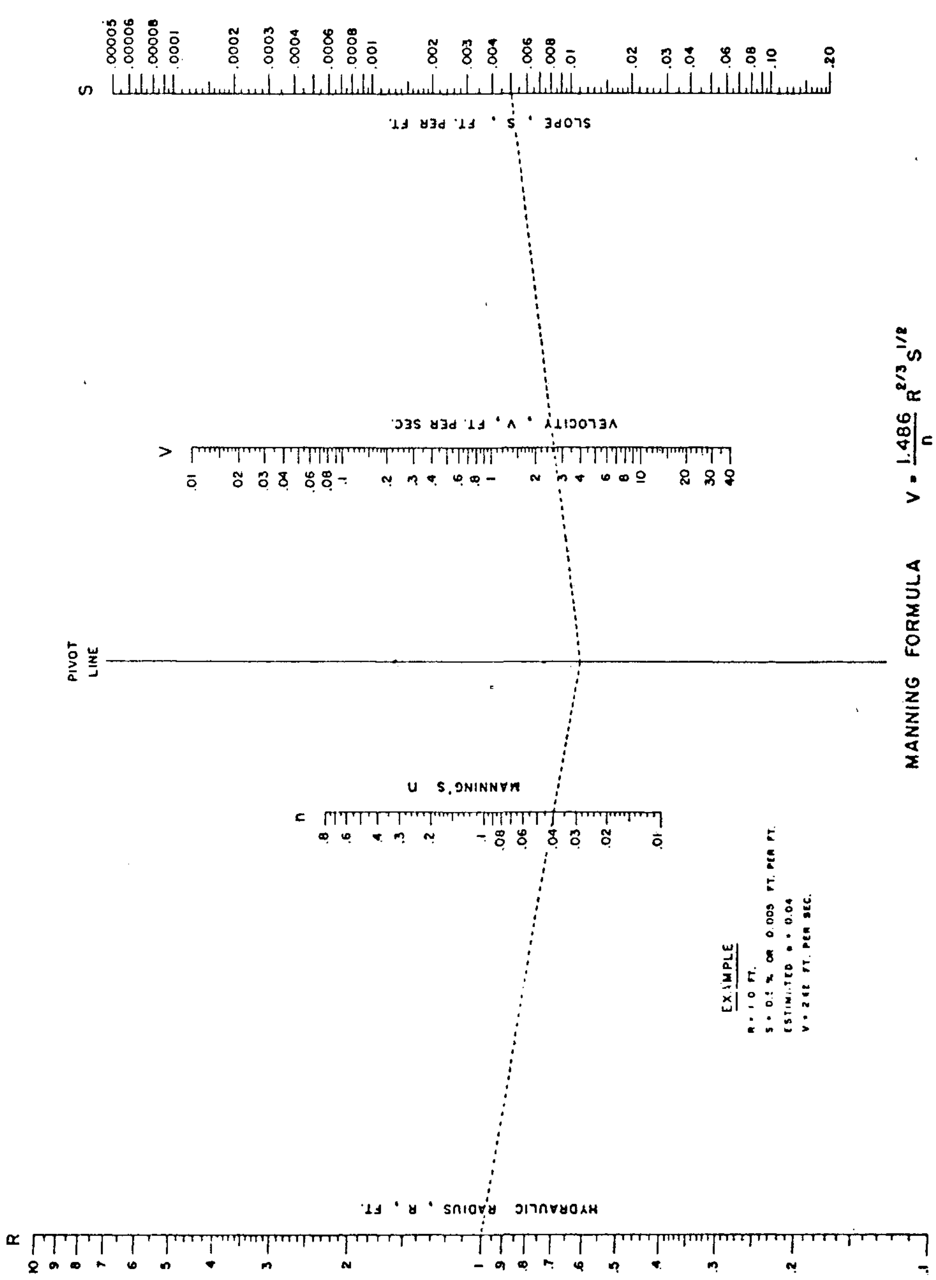
flow area and hydraulic radius. This is accomplished by reading vertically along the "d" scale at the right to the intersection with the appropriate (righthand) "t" curve (or the asymptote to the curve family). This intersection defines the desired "R." The intersection of this "R" value and the lefthand curve for "t" will give the desired "A."

(13) Enter Figure 4-5 for retardance "C" with hydraulic radius and channel slope. Read vertically along the hydraulic radius scale to intersection of the correct slope curve and project this intersection horizontally to the velocity scale. If product of flow area and velocity is greater than the 10-year, 24-hour peak discharge, a lesser depth should be tried in step (11) and vice versa.

(14) Since the waterways are rather shallow, trials beyond the third one are usually unwarranted.

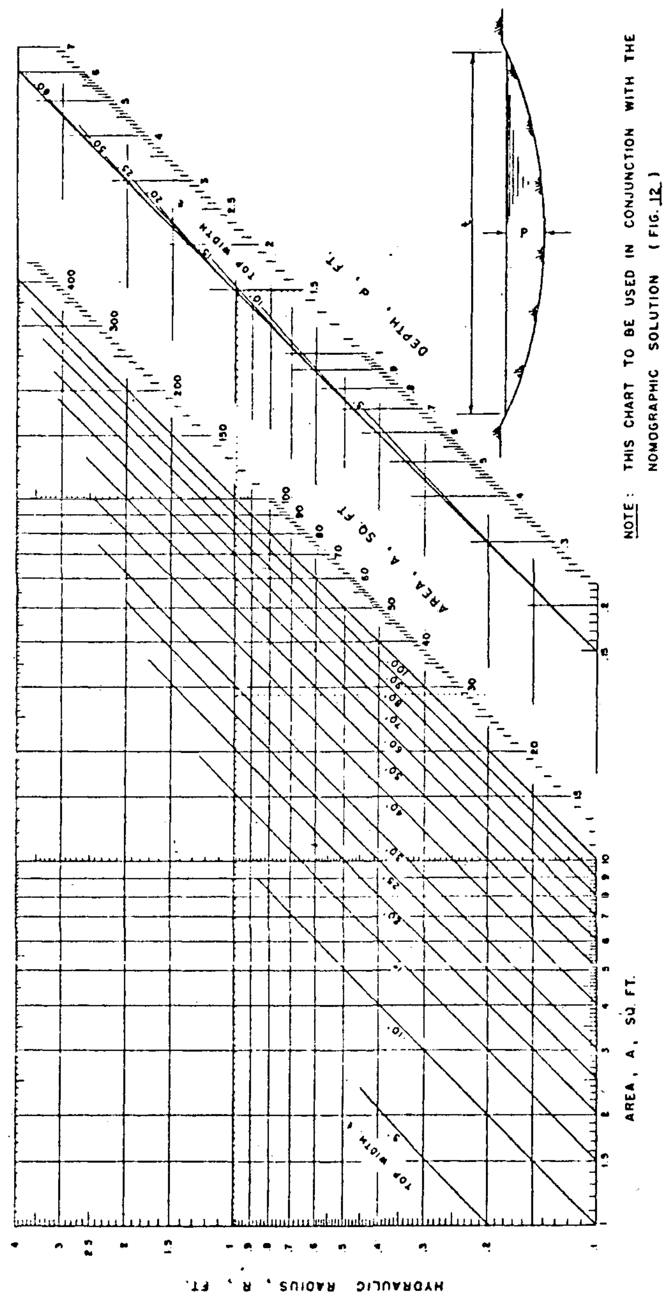
(15) Freeboard of 0.5-foot should be added to the depth required to satisfy capacity requirement. Figure 4-4 can be used to determine a width corresponding to this final depth (using the pivot point from step 9) and any width-depth combinations needed to build the waterway.

Figure 4-2. Solution of the Manning Formula.



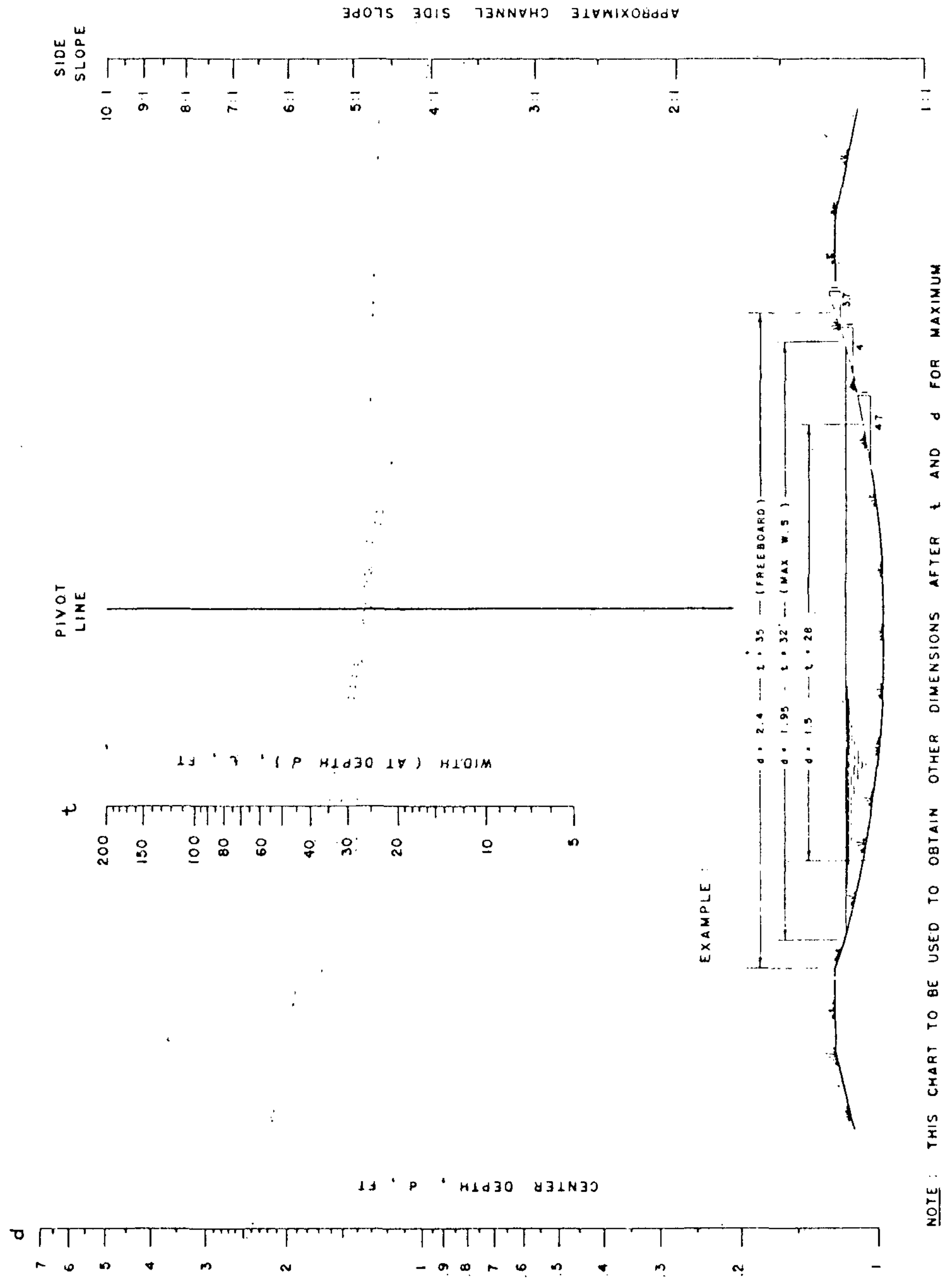
Source: U.S. Department of Agriculture, Soil Conservation Service, Handbook of Channel Design for Soil and Water Conservation, by Stillwater Outdoor Hydraulic Laboratory (revised June, 1954), p. 13.

Figure 4-3. Dimensions of Parabolic Channels.



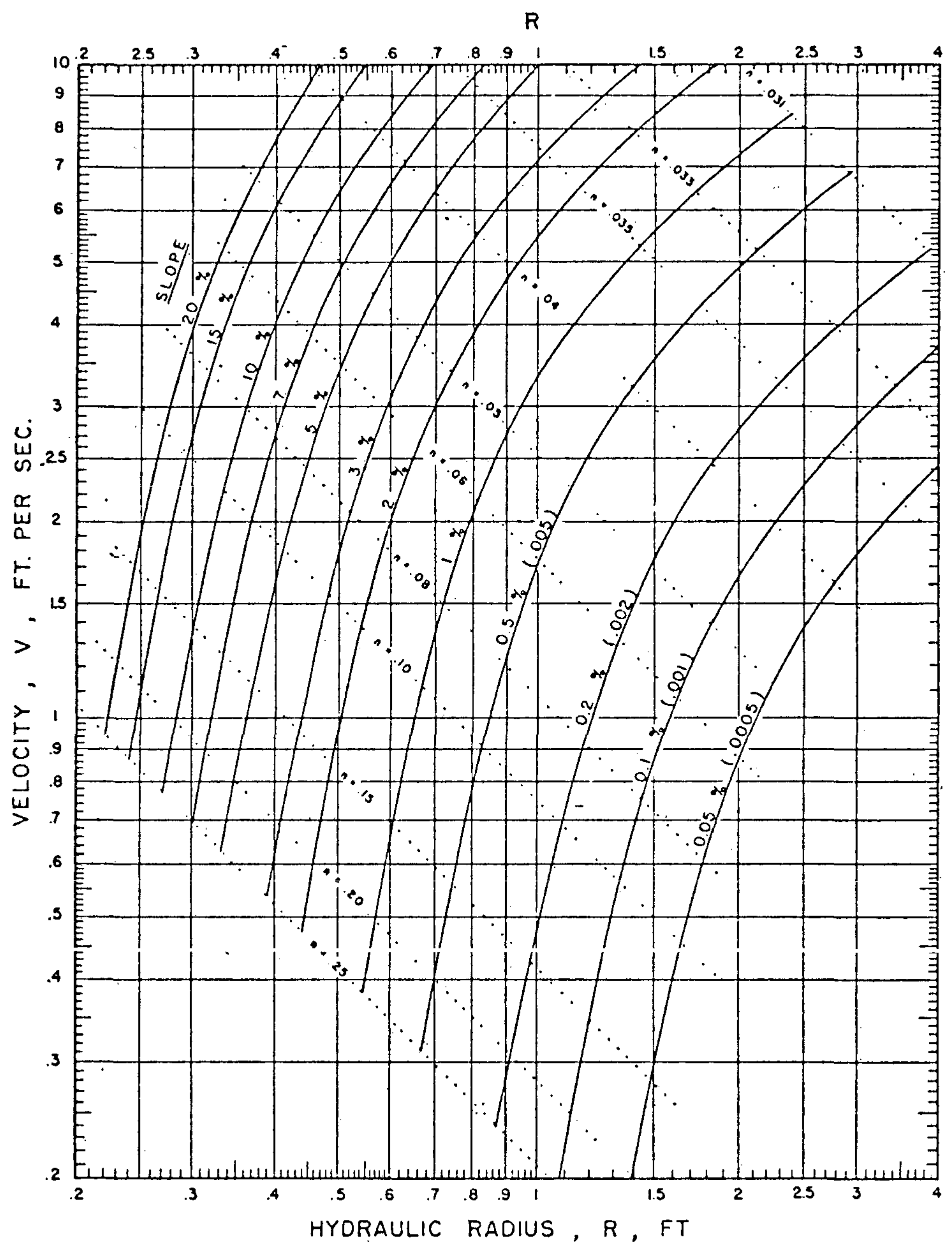
Source: U.S. Department of Agriculture, Soil Conservation Service, Handbook of Channel Design for Soil and Water Conservation, by Stillwater Outdoor Hydraulic Laboratory (revised June, 1954), p. 13.

Figure 4-4. Solution for Dimensions of Parabolic Channels.



Source: U.S. Department of Agriculture, Soil Conservation Service, Handbook of Channel Design for Soil and Water Conservation, by Stillwater Outdoor Hydraulic Laboratory (revised, June 1954), p. 24.

Figure 4-5. Solution of the Manning Formula for Retardance C (Moderate Vegetal Retardance).



Source: U.S. Department of Agriculture, Soil Conservation Service, Handbook of Channel Design for Soil and Water Conservation, by Stillwater Outdoor Hydraulic Laboratory (revised June, 1954), p. 28.

Other Waterway Design Considerations

The floor of the gully must be made to act as a continuation of the steeper portion of the waterway. It is possible that at the change in gradient either of two problems will develop. Sediment deposition may kill the vegetation, or scour may develop. If sediment is the problem, it will have to be stopped upgradient. If scour is the problem, it must be interpreted as an indication that a structural solution is needed. It seems worth repeating that if the outlet conditions of a waterway cannot be made stable, a shaped waterway is not the correct solution to a gully. If the lower level of the gully is pure, sterile sand, there is little hope for a waterway. The sand is not likely to sustain grasses. If the gully bottom is too narrow to allow non-erosive disposal velocities, trouble is in sight.

One of the biggest problems with shaping and grassing a gully is that the lower level of the gully is often full of active seeps. This is especially true in Coastal Plain locations. The only approach to solving this problem in the Coastal Plain area is to provide "tile drainage." Filter action is not a big problem in these situations, natural phenomena having already taken care of it. Commercially processed material meeting requirements for ASTM designation C33 for concrete sand or No. 8 gravel should work satisfactorily as a filter with drain tile having perforations (slots) of 1/8-inch size or smaller.

Diversion

Diversion is mentioned as a possible solution to gully problems with much reluctance, though historically it has been considered as having potential application to virtually all gullies (3, p. 18). The reason for this reluctance is that due to improper use of the concept, diversion has had a poor track record in Alabama creating many new gullies. It has been too often used as a "cop out" when only more expensive structural work offered hope of success.

Though it has been the practice in Alabama to design diversions to slightly less stringent velocity limitations than those used for waterways, it is suggested that the strictures of Table 4-2 be observed in diversion design. The justification for this viewpoint lies in the fact that gully control diversions are long-term measures which tend to experience low maintenance. Poor protective vegetation is expected.

Table 4-4 may be used to select a waterway size which will safely carry the required rate of discharge. The chart is used by starting at the desired discharge rate on the left and reading to the right to the columns vertically beneath the allowable V_1 value. Values in the columns to the left of this also offer valid but more conservative solutions. The table values include freeboard, but an appropriate allowance for fill settlement, varying upward from 0.3 foot, should be added to channel depth. Figure 4-4 can be used to secure added dimensions to assure construction to the correct parabolic shape--an important procedure.

The critical problem with diversion is providing a safe disposal area. There is no such thing in highly erodible soils. A safe disposal area is not ever a steep area. Basically, a grassed disposal area for a diversion is little more than a waterway. Unless it will spread the water thinly and carry it to a lower elevation at a non-erosive velocity, it will not work. It will become a new gully. Unless this test of realism can be applied to a vegetated disposal area--that it get the required flow to the lower elevation where safe, controlled, stable conditions can be depended upon--diversions are not indicated as a potential solution. In other words, the disposal area should essentially be designed as a waterway.

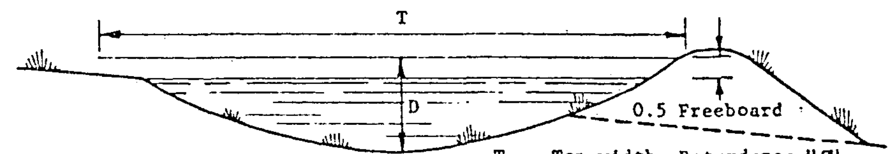
Diversions can of course be validly used to collect and transmit runoff to a gradient control structure. This will prove to be their main application, if the criteria discussed above are strictly applied. Diversions share in common with shaped waterways the problem of being highly susceptible to scour before vegetation can develop. Therefore, the procedure outlined for including "as-built" conditions in the design of waterways applies equally to

Table 4-4. Parabolic Diversion Design Chart.

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "C" — Grade = 0.25%

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15																											
20																											
25	11	2.9	1.6																								
30	13	2.8	1.7																								
35	15	2.8	1.7																								
40	17	2.8	1.8	11	3.2	2.1																					
45	19	2.7	1.8	13	3.1	2.2																					
50	21	2.7	1.8	14	3.1	2.2																					
55	23	2.7	1.8	15	3.1	2.3																					
60	25	2.7	1.8	17	3.0	2.3																					
65	27	2.7	1.8	18	3.0	2.3																					
70	29	2.7	1.9	19	3.0	2.3	14	3.6	2.7																		
75	31	2.7	1.9	21	3.0	2.3	15	3.5	2.8																		
80	33	2.7	1.9	22	3.0	2.4	16	3.5	2.8																		
90	37	2.7	1.9	25	3.0	2.4	17	3.5	2.8																		
100	41	2.7	1.9	28	3.0	2.4	19	3.5	2.9																		
110	45	2.7	1.9	30	3.0	2.4	21	3.4	2.9																		
120	49	2.7	1.9	33	3.0	2.4	23	3.4	2.9	16	4.1	3.3															
130	53	2.7	1.9	36	3.0	2.4	25	3.4	2.9	18	4.1	3.3															
140	57	2.7	1.9	38	3.0	2.4	27	3.4	2.9	19	4.0	3.4															
150	61	2.7	1.9	41	3.0	2.4	29	3.4	2.9	20	4.0	3.4															
160	65	2.7	1.9	44	3.0	2.4	30	3.4	3.0	21	4.0	3.4															
170	69	2.7	1.9	46	3.0	2.4	32	3.4	3.0	23	4.0	3.4	18	4.5	3.8												
180	73	2.7	1.9	49	3.0	2.4	34	3.4	3.0	24	4.0	3.5	19	4.5	3.8												
190	77	2.7	1.9	52	3.0	2.4	36	3.4	3.0	25	4.0	3.5	20	4.5	3.9												
200	81	2.7	1.9	55	3.0	2.4	38	3.4	3.0	27	3.9	3.5	21	4.4	3.9												
220	89	2.7	1.9	60	3.0	2.4	42	3.4	3.0	29	3.9	3.5	23	4.4	3.9												
240	97	2.7	1.9	65	3.0	2.5	45	3.4	3.0	32	3.9	3.6	25	4.4	4.0												
260				71	3.0	2.5	49	3.4	3.0	34	3.9	3.6	27	4.4	4.0	21	5.1	4.3									
280				76	3.0	2.5	53	3.4	3.0	37	3.9	3.6	29	4.4	4.0	22	5.1	4.3									
300				82	3.0	2.5	57	3.4	3.0	40	3.9	3.6	31	4.3	4.1	24	5.0	4.4									



T = Top width, Retardance "C"
D = Depth, Retardance "C"
V_2 = Velocity, Retardance "C"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge.)

Source: U. S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), pp. 9-21 to 9-26.

Table 4-4 (Continued).

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "C"   Grade = 0.5%

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	10	2.1	1.6																								
20	13	2.1	1.7																								
25	16	2.1	1.7	10	2.4	2.1																					
30	20	2.1	1.7	12	2.4	2.2	9	2.7	2.5																		
35	23	2.1	1.7	14	2.4	2.3	11	2.6	2.6																		
40	26	2.1	1.7	16	2.3	2.3	12	2.6	2.7																		
45	29	2.0	1.7	18	2.3	2.3	13	2.5	2.8																		
50	32	2.0	1.7	20	2.3	2.4	15	2.5	2.8	11	2.9	3.2															
55	35	2.0	1.7	22	2.3	2.4	16	2.5	2.8	12	2.9	3.3															
60	39	2.0	1.7	24	2.3	2.4	18	2.5	2.8	13	2.9	3.3															
65	42	2.0	1.8	26	2.3	2.4	19	2.5	2.9	14	2.9	3.3															
70	45	2.0	1.8	28	2.3	2.4	21	2.5	2.9	15	2.8	3.4															
75	48	2.0	1.8	30	2.3	2.4	22	2.5	2.9	16	2.8	3.4	12	3.2	3.7												
80	51	2.0	1.8	32	2.3	2.4	23	2.5	2.9	17	2.8	3.4	13	3.2	3.8												
90	57	2.0	1.8	35	2.3	2.4	26	2.5	2.9	19	2.8	3.4	15	3.2	3.8												
100	64	2.0	1.8	39	2.3	2.4	29	2.5	2.9	21	2.8	3.5	16	3.1	3.9	13	3.5	4.1									
110	70	2.0	1.8	43	2.3	2.4	32	2.5	2.9	23	2.8	3.5	18	3.1	3.9	14	3.5	4.2									
120	76	2.0	1.8	47	2.3	2.4	35	2.5	2.9	25	2.8	3.5	19	3.1	3.9	15	3.4	4.3									
130	83	2.0	1.8	51	2.3	2.4	38	2.5	2.9	27	2.8	3.5	21	3.1	4.0	17	3.4	4.4									
140	89	2.0	1.8	55	2.3	2.4	41	2.5	2.9	29	2.8	3.5	22	3.1	4.0	18	3.4	4.3									
150	95	2.0	1.8	59	2.3	2.4	44	2.5	2.9	31	2.8	3.5	24	3.1	4.0	19	3.4	4.4	15	3.8	4.8						
160				62	2.3	2.4	46	2.5	2.9	33	2.8	3.5	25	3.1	4.0	20	3.4	4.4	16	3.8	4.8						
170				66	2.3	2.4	49	2.5	2.9	35	2.8	3.6	27	3.1	4.0	22	3.4	4.4	17	3.8	4.9						
180				70	2.3	2.4	52	2.5	2.9	37	2.8	3.6	29	3.1	4.0	23	3.4	4.5	18	3.8	4.9						
190				74	2.3	2.4	55	2.5	2.9	39	2.8	3.6	30	3.1	4.0	24	3.4	4.5	19	3.8	5.0						
200				78	2.3	2.4	58	2.5	2.9	41	2.8	3.6	32	3.1	4.0	25	3.4	4.5	20	3.8	5.0	16	4.2	5.2			
220				86	2.3	2.4	64	2.5	2.9	45	2.8	3.6	35	3.1	4.0	28	3.4	4.5	22	3.7	5.0	18	4.2	5.3			
240				93	2.3	2.4	69	2.5	2.9	49	2.8	3.6	38	3.0	4.1	30	3.4	4.5	24	3.7	5.0	20	4.2	5.4			
260							75	2.5	2.9	53	2.8	3.6	41	3.0	4.1	33	3.4	4.5	26	3.7	5.0	21	4.1	5.4			
280							81	2.5	3.0	57	2.8	3.6	44	3.0	4.1	35	3.3	4.6	28	3.7	5.0	23	4.1	5.5	19	4.6	5.8
300							87	2.5	3.0	61	2.8	3.6	47	3.0	4.1	38	3.3	4.6	30	3.6	5.0	24	4.1	5.5	20	4.6	5.8

T = Top Width, Retardance "C"
D = Depth, Retardance "C"
V_2 = Velocity, Retardance "C"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge.)

Table 4-4 (Continued).

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "C"

Grade = 0.75%

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	14	1.8	1.5																								
20	18	1.8	1.5	10	2.0	2.2																					
25	23	1.8	1.5	13	2.0	2.2																					
30	27	1.8	1.5	15	2.0	2.2	11	2.2	2.7																		
35	32	1.8	1.5	18	2.0	2.3	13	2.2	2.7	10	2.4	3.1															
40	37	1.8	1.5	20	2.0	2.3	15	2.2	2.8	11	2.4	3.2															
45	41	1.8	1.6	23	2.0	2.3	17	2.2	2.8	13	2.3	3.2															
50	45	1.8	1.6	25	2.0	2.3	18	2.1	2.9	14	2.3	3.3	10	2.7	3.7												
55	50	1.8	1.6	28	2.0	2.3	20	2.1	2.9	16	2.3	3.3	11	2.6	3.8												
60	54	1.8	1.6	30	2.0	2.3	22	2.1	2.9	17	2.3	3.3	12	2.6	3.8												
65	59	1.8	1.6	33	2.0	2.3	24	2.1	2.9	18	2.3	3.3	13	2.6	3.8	11	2.9	4.1									
70	63	1.8	1.6	35	2.0	2.3	25	2.1	2.9	20	2.3	3.3	14	2.6	3.9	12	2.9	4.2									
75	68	1.8	1.6	38	2.0	2.3	27	2.1	2.9	21	2.3	3.3	15	2.6	3.9	13	2.8	4.2									
80	72	1.8	1.6	40	2.0	2.3	29	2.1	2.9	23	2.3	3.3	16	2.6	3.9	14	2.8	4.3									
90	81	1.8	1.6	45	2.0	2.3	33	2.1	2.9	25	2.3	3.4	18	2.6	4.0	15	2.8	4.4	12	3.1	4.6						
100	90	1.8	1.6	50	2.0	2.3	36	2.1	2.9	28	2.3	3.4	20	2.6	4.0	17	2.8	4.4	13	3.1	4.8						
110	99	1.8	1.6	55	2.0	2.3	40	2.1	2.9	31	2.3	3.4	22	2.5	4.0	18	2.8	4.5	15	3.1	4.8						
120				60	2.0	2.3	43	2.1	2.9	34	2.3	3.4	24	2.5	4.0	20	2.8	4.5	16	3.0	4.8	13	3.4	5.2			
130				65	2.0	2.4	47	2.1	2.9	36	2.3	3.4	26	2.5	4.0	21	2.7	4.5	17	3.0	4.9	14	3.3	5.3			
140				70	2.0	2.4	50	2.1	2.9	39	2.3	3.4	28	2.5	4.1	23	2.7	4.5	19	3.0	4.9	15	3.3	5.3			
150				75	2.0	2.4	54	2.1	2.9	42	2.3	3.4	30	2.5	4.1	25	2.7	4.5	20	3.0	4.9	16	3.3	5.3			
160				80	2.0	2.4	58	2.1	2.9	45	2.3	3.4	32	2.5	4.1	26	2.7	4.5	21	3.0	4.9	17	3.3	5.4	14	3.6	5.8
170				85	2.0	2.4	61	2.1	2.9	47	2.3	3.4	34	2.5	4.1	28	2.7	4.5	22	3.0	5.0	18	3.3	5.4	15	3.6	5.8
180				89	2.0	2.4	65	2.1	2.9	50	2.3	3.4	36	2.5	4.1	29	2.7	4.5	24	3.0	5.0	19	3.3	5.5	16	3.6	5.9
190				94	2.0	2.4	68	2.1	2.9	53	2.3	3.4	38	2.5	4.1	31	2.7	4.6	25	3.0	5.0	21	3.3	5.5	17	3.6	5.9
200				99	2.0	2.4	72	2.1	3.0	55	2.3	3.4	40	2.5	4.1	33	2.7	4.6	26	3.0	5.0	22	3.2	5.5	18	3.6	5.9
220							79	2.1	3.0	61	2.3	3.4	44	2.5	4.1	36	2.7	4.6	29	3.0	5.0	24	3.2	5.5	19	3.6	5.9
240							86	2.1	3.0	66	2.3	3.4	48	2.5	4.1	39	2.7	4.6	32	3.0	5.0	26	3.2	5.5	21	3.6	6.0
260							93	2.1	3.0	72	2.3	3.4	52	2.5	4.1	42	2.7	4.6	34	3.0	5.0	28	3.2	5.5	23	3.6	6.0
280										77	2.3	3.4	56	2.5	4.1	45	2.7	4.6	37	3.0	5.0	30	3.2	5.5	24	3.5	6.0
300										83	2.3	3.5	60	2.5	4.1	49	2.7	4.6	39	3.0	5.0	32	3.2	5.5	26	3.5	6.0

T = Top Width, Retardance "C"
D = Depth, Retardance "C"
V_2 = Velocity, Retardance "C"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge)

Table 4-4 (Continued).

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "C" Grade = 1.0%

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	16	1.6	1.5	10	1.8	2.0						
20	22	1.6	1.5	13	1.8	2.1						
25	27	1.6	1.5	17	1.8	2.1	11	2.0	2.6			
30	32	1.6	1.5	20	1.8	2.1	13	2.0	2.7	11	2.1	3.0
35	37	1.6	1.5	23	1.8	2.2	15	2.0	2.8	12	2.1	3.1
40	43	1.6	1.5	26	1.8	2.2	17	1.9	2.8	14	2.1	3.1
45	48	1.6	1.5	29	1.8	2.2	19	1.9	2.8	16	2.1	3.2
50	53	1.6	1.5	33	1.8	2.2	22	1.9	2.8	17	2.1	3.2
55	58	1.6	1.5	36	1.8	2.2	24	1.9	2.8	19	2.0	3.3
60	64	1.6	1.5	39	1.8	2.2	26	1.9	2.8	21	2.0	3.3
65	69	1.6	1.5	42	1.8	2.2	28	1.9	2.8	22	2.0	3.3
70	74	1.6	1.5	45	1.8	2.2	30	1.9	2.8	24	2.0	3.3
75	79	1.6	1.5	49	1.8	2.2	32	1.9	2.9	26	2.0	3.3
80	84	1.6	1.5	52	1.8	2.2	34	1.9	2.9	27	2.0	3.3
90	95	1.6	1.5	58	1.8	2.2	38	1.9	2.9	31	2.0	3.3
100				65	1.8	2.2	43	1.9	2.9	34	2.0	3.3
110				71	1.8	2.2	47	1.9	2.9	37	2.0	3.3
120				77	1.8	2.2	51	1.9	2.9	41	2.0	3.3
130				84	1.8	2.2	55	1.9	2.9	44	2.0	3.3
140				90	1.8	2.2	59	1.9	2.9	47	2.0	3.3
150				96	1.8	2.2	64	1.9	2.9	51	2.0	3.3
160							68	1.9	2.9	54	2.0	3.3
170							72	1.9	2.9	57	2.0	3.3
180							76	1.9	2.9	61	2.0	3.4
190							80	1.9	2.9	64	2.0	3.4
200							84	1.9	2.9	67	2.0	3.4
220							93	1.9	2.9	74	2.0	3.4
240										81	2.0	3.4
260										87	2.0	3.4
280										94	2.0	3.4
300												

Q	V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15															
20															
25															
30															
35															
40	10	2.3	3.7												
45	12	2.3	3.7												
50	13	2.3	3.7	10	2.5	4.2									
55	14	2.3	3.8	11	2.5	4.3									
60	15	2.2	3.8	12	2.5	4.3									
65	17	2.2	3.8	13	2.5	4.3	10	2.7	4.7						
70	18	2.2	3.9	14	2.5	4.4	11	2.7	4.7						
75	19	2.2	3.9	15	2.5	4.5	12	2.7	4.7						
80	20	2.2	3.9	16	2.5	4.5	13	2.7	4.9						
90	23	2.2	3.9	17	2.4	4.5	14	2.7	4.9	12	2.9	5.2			
100	25	2.2	3.9	19	2.4	4.5	16	2.7	4.9	13	2.9	5.3			
110	28	2.2	3.9	21	2.4	4.5	17	2.6	5.0	14	2.9	5.3	12	3.1	5.7
120	30	2.2	4.0	23	2.4	4.5	19	2.6	5.0	16	2.9	5.4	13	3.1	5.7
130	33	2.2	4.0	25	2.4	4.5	20	2.6	5.0	17	2.9	5.4	14	3.1	5.8
140	35	2.2	4.0	27	2.4	4.5	22	2.6	5.0	18	2.8	5.5	15	3.1	5.8
150	38	2.2	4.0	29	2.4	4.5	23	2.6	5.0	19	2.8	5.5	17	3.1	5.8
160	40	2.2	4.0	30	2.4	4.5	25	2.6	5.0	20	2.8	5.5	18	3.0	6.0
170	43	2.2	4.0	32	2.4	4.5	26	2.5	5.0	22	2.8	5.5	19	3.0	6.0
180	45	2.2	4.0	34	2.4	4.5	28	2.6	5.0	23	2.8	5.5	20	3.0	6.0
190	48	2.2	4.0	36	2.4	4.5	29	2.6	5.0	24	2.8	5.5	21	3.0	6.0
200	50	2.2	4.0	38	2.4	4.5	31	2.6	5.0	25	2.8	5.5	22	3.0	6.0
220	55	2.2	4.0	42	2.4	4.5	34	2.6	5.0	28	2.8	5.5	24	3.0	6.0
240	60	2.2	4.0	45	2.4	4.5	37	2.6	5.0	30	2.8	5.5	26	3.0	6.0
260	65	2.2	4.0	49	2.4	4.5	40	2.6	5.0	33	2.8	5.5	28	3.0	6.0
280	70	2.2	4.0	53	2.4	4.5	43	2.6	5.0	36	2.8	5.5	30	3.0	6.0
300	75	2.2	4.0	57	2.4	4.5	46	2.5	5.0	38	2.8	5.5	32	3.0	6.0

T = Top Width, Retardance "C"
D = Depth, Retardance "C"
V_2 = Velocity, Retardance "C"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge.)

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "C" Grade = 1.5%

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	21	1.4	1.4	14	1.6	1.9																					
20	28	1.4	1.4	18	1.5	1.9	12	1.7	2.5																		
25	35	1.4	1.4	23	1.5	1.9	15	1.7	2.6	10	1.9	3.2															
30	42	1.4	1.4	27	1.5	1.9	18	1.7	2.6	12	1.8	3.2	10	2.0	3.6												
35	49	1.4	1.4	32	1.5	2.0	21	1.6	2.6	14	1.8	3.3	11	1.9	3.7	10	2.1	4.1									
40	56	1.4	1.4	36	1.5	2.0	24	1.6	2.6	16	1.8	3.3	13	1.9	3.7	11	2.1	4.2									
45	63	1.4	1.4	41	1.5	2.0	27	1.6	2.6	18	1.8	3.4	15	1.9	3.8	12	2.0	4.3									
50	70	1.4	1.4	45	1.5	2.0	30	1.6	2.7	20	1.8	3.4	16	1.9	3.9	13	2.0	4.3	10	2.3	4.8						
55	76	1.4	1.5	50	1.5	2.0	33	1.6	2.7	22	1.8	3.4	18	1.9	3.9	14	2.0	4.3	11	2.3	4.9						
60	83	1.4	1.5	54	1.5	2.0	35	1.6	2.7	24	1.8	3.4	19	1.9	3.9	16	2.0	4.4	12	2.3	4.9	10	2.4	5.2			
65	90	1.4	1.5	58	1.5	2.0	38	1.6	2.7	26	1.8	3.4	21	1.9	3.9	17	2.0	4.4	13	2.2	5.0	11	2.4	5.3			
70	97	1.4	1.5	63	1.5	2.0	41	1.6	2.7	28	1.8	3.4	22	1.9	3.9	18	2.0	4.4	14	2.2	5.0	12	2.4	5.4	10	2.6	5.6
75				67	1.5	2.0	44	1.6	2.7	30	1.8	3.4	24	1.9	3.9	19	2.0	4.4	15	2.2	5.0	12	2.4	5.4	11	2.6	5.6
80				72	1.5	2.0	47	1.6	2.7	32	1.8	3.4	26	1.9	3.9	21	2.0	4.4	16	2.2	5.0	13	2.4	5.4	12	2.5	5.8
90				80	1.5	2.0	53	1.6	2.7	36	1.8	3.5	29	1.9	3.9	23	2.0	4.4	18	2.2	5.0	15	2.4	5.4	13	2.5	5.9
100				89	1.5	2.0	59	1.6	2.7	39	1.8	3.5	32	1.9	3.9	26	2.0	4.5	20	2.2	5.0	17	2.4	5.4	14	2.5	6.0
110				98	1.5	2.0	64	1.6	2.7	43	1.8	3.5	35	1.9	3.9	28	2.0	4.5	22	2.2	5.0	18	2.3	5.5	15	2.5	6.0
120							70	1.6	2.7	47	1.8	3.5	38	1.9	4.0	31	2.0	4.5	24	2.2	5.0	20	2.3	5.5	17	2.5	6.0
130							76	1.6	2.7	51	1.8	3.5	41	1.9	4.0	33	2.0	4.5	26	2.2	5.0	21	2.3	5.5	18	2.5	6.0
140							82	1.6	2.7	55	1.8	3.5	44	1.9	4.0	36	2.0	4.5	27	2.2	5.0	23	2.3	5.5	19	2.5	6.0
150							87	1.6	2.7	59	1.8	3.5	47	1.9	4.0	39	2.0	4.5	29	2.2	5.0	25	2.3	5.5	21	2.5	6.0
160							93	1.6	2.7	63	1.8	3.5	51	1.9	4.0	41	2.0	4.5	31	2.2	5.0	26	2.3	5.5	22	2.5	6.0
170							99	1.6	2.7	67	1.8	3.5	54	1.9	4.0	44	2.0	4.5	33	2.2	5.0	28	2.3	5.5	23	2.5	6.0
180										70	1.8	3.5	57	1.9	4.0	46	2.0	4.5	35	2.2	5.0	29	2.3	5.5	25	2.5	6.0
190										74	1.8	3.5	60	1.9	4.0	49	2.0	4.5	37	2.2	5.0	31	2.3	5.5	26	2.5	6.0
200										78	1.8	3.5	63	1.9	4.0	51	2.0	4.5	39	2.2	5.0	33	2.3	5.5	27	2.5	6.0
220										86	1.8	3.5	69	1.9	4.0	56	2.0	4.5	43	2.2	5.0	36	2.3	5.5	30	2.5	6.0
240										93	1.8	3.5	75	1.9	4.0	61	2.0	4.5	47	2.2	5.0	39	2.3	5.5	33	2.5	6.0
260													82	1.9	4.0	66	2.0	4.5	51	2.2	5.0	42	2.3	5.5	35	2.5	6.0
280													88	1.9	4.0	71	2.0	4.5	54	2.2	5.0	46	2.3	5.5	38	2.5	6.0
300													94	1.9	4.0	76	2.0	4.5	58	2.2	5.0	49	2.3	5.5	41	2.5	6.0

T = Top width, Retardance "C"
D = Depth, Retardance "C"
V_2 = Velocity, Retardance "C"
V_1 = Velocity, Retardance "D"
(Settlement to be added to top of ridge.)

Table 4-4 (Continued).

Table 4-4 (Continued).

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "C" Grade = 2.0%

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	27	1.3	1.3	16	1.4	1.9	11	1.5	2.4																		
20	35	1.3	1.3	21	1.4	1.9	15	1.5	2.4	11	1.6	3.0															
25	44	1.3	1.3	27	1.4	1.9	19	1.5	2.4	13	1.6	3.0	10	1.8	3.7												
30	53	1.3	1.3	32	1.4	1.9	23	1.5	2.5	16	1.6	3.0	11	1.7	3.7	10	1.8	4.2									
35	61	1.3	1.3	37	1.4	1.9	26	1.5	2.5	19	1.6	3.1	13	1.7	3.8	11	1.8	4.2									
40	70	1.3	1.3	42	1.4	1.9	30	1.5	2.5	21	1.6	3.1	15	1.7	3.8	12	1.8	4.3	10	2.0	4.7						
45	78	1.3	1.4	48	1.4	1.9	34	1.5	2.5	24	1.6	3.1	17	1.7	3.8	14	1.8	4.3	11	1.9	4.8						
50	87	1.3	1.4	53	1.4	1.9	38	1.5	2.5	26	1.6	3.1	19	1.7	3.8	15	1.8	4.3	13	1.9	4.8	10	2.1	5.3			
55	95	1.3	1.4	58	1.4	1.9	41	1.5	2.5	29	1.6	3.1	21	1.7	3.8	17	1.8	4.3	14	1.9	4.9	11	2.1	5.3			
60				63	1.4	1.9	45	1.5	2.5	32	1.6	3.1	23	1.7	3.9	18	1.8	4.4	15	1.9	4.9	12	2.1	5.3	10	2.2	5.7
65				68	1.4	1.9	49	1.5	2.5	34	1.6	3.1	24	1.7	3.9	20	1.8	4.4	16	1.9	4.9	13	2.1	5.4	11	2.2	5.7
70				73	1.4	1.9	52	1.5	2.5	37	1.6	3.1	26	1.7	3.9	22	1.8	4.4	18	1.9	4.9	14	2.1	5.4	12	2.2	5.8
75				78	1.4	1.9	56	1.5	2.5	39	1.6	3.1	28	1.7	3.9	23	1.8	4.4	19	1.9	4.9	15	2.1	5.4	13	2.2	5.9
80				83	1.4	2.0	60	1.5	2.5	42	1.6	3.1	30	1.7	3.9	24	1.8	4.4	20	1.9	4.9	16	2.1	5.4	14	2.2	5.9
90				94	1.4	2.0	67	1.5	2.5	47	1.6	3.2	34	1.7	3.9	28	1.8	4.4	22	1.9	4.9	18	2.1	5.5	15	2.2	5.9
100							74	1.5	2.5	52	1.6	3.2	37	1.7	3.9	31	1.8	4.4	25	1.9	5.0	20	2.1	5.5	17	2.2	6.0
110							81	1.5	2.5	57	1.6	3.2	41	1.7	3.9	34	1.8	4.4	27	1.9	5.0	22	2.0	5.5	19	2.2	6.0
120							89	1.5	2.5	62	1.6	3.2	45	1.7	3.9	37	1.8	4.4	30	1.9	5.0	24	2.0	5.5	20	2.2	6.0
130							96	1.5	2.5	67	1.6	3.2	48	1.7	3.9	40	1.8	4.5	32	1.9	5.0	26	2.0	5.5	22	2.2	6.0
140										73	1.6	3.2	52	1.7	4.0	42	1.8	4.5	35	1.9	5.0	28	2.0	5.5	23	2.2	6.0
150										78	1.6	3.2	56	1.7	4.0	46	1.8	4.5	37	1.9	5.0	30	2.0	5.5	25	2.2	6.0
160										83	1.6	3.2	59	1.7	4.0	48	1.8	4.5	39	1.9	5.0	32	2.0	5.5	27	2.2	6.0
170										88	1.6	3.2	63	1.7	4.0	51	1.8	4.5	42	1.9	5.0	34	2.0	5.5	28	2.2	6.0
180										93	1.6	3.2	67	1.7	4.0	54	1.8	4.5	44	1.9	5.0	36	2.0	5.5	30	2.2	6.0
190										98	1.6	3.2	70	1.7	4.0	57	1.8	4.5	47	1.9	5.0	38	2.0	5.5	32	2.2	6.0
200													74	1.7	4.0	60	1.8	4.5	49	1.9	5.0	40	2.0	5.5	33	2.2	6.0
220													81	1.7	4.0	66	1.8	4.5	54	1.9	5.0	44	2.0	5.5	37	2.2	6.0
240													88	1.7	4.0	72	1.8	4.5	59	1.9	5.0	48	2.0	5.5	40	2.2	6.0
260													96	1.7	4.0	78	1.8	4.5	64	1.9	5.0	51	2.0	5.5	43	2.2	6.0
280																84	1.8	4.5	69	1.9	5.0	55	2.0	5.5	46	2.2	6.0
300																90	1.8	4.5	73	1.9	5.0	59	2.0	5.5	50	2.2	6.0

T = Top width, Retardance "C"
D = Depth, Retardance "C"
V_2 = Velocity, Retardance "C"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge.)

diversions, if it is not possible to develop vegetation before placing the diversion in operation.

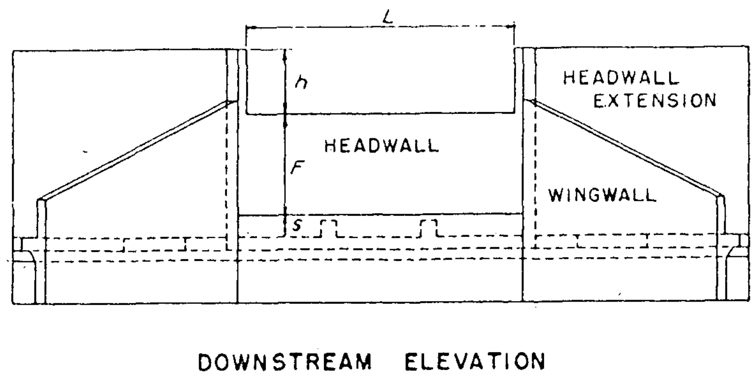
Drop Spillways

Straight drop and box drop spillways are much alike in their adaptations. In gully stabilization work they may be used either to reduce waterway gradient in the gully body or to bring headward movement to a standstill. They offer two primary advantages: 1) they handle flow with good hydraulic efficiency and, 2) they are hard to clog with trash. They have a major limitation in that they undermine themselves in erodible materials.

Detailed design of drop spillways requires the services of one specially trained in this type of structure. The Soil Conservation Service has compiled a design manual, National Engineering Handbook Section 11, which treats design of these structures with relative completeness (4). Standard and special designs of a variety of reinforced concrete drop spillways are available at SCS design offices and various other locations. The following paragraphs provide estimating information.

Figure 4-6 illustrates the terminology used in the two estimating tools, Figures 4-7 and Table 4-5. Only three of the terms are needed: F = overfall height in feet, h = weir depth in feet, and L = weir length in feet.

Figure 4-6. Symbols for Straight Drop Spillway.



Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 6-10.

Weir combinations are selected from Figure 4-7, and quantities corresponding to these dimensions are taken from Table 4-5.

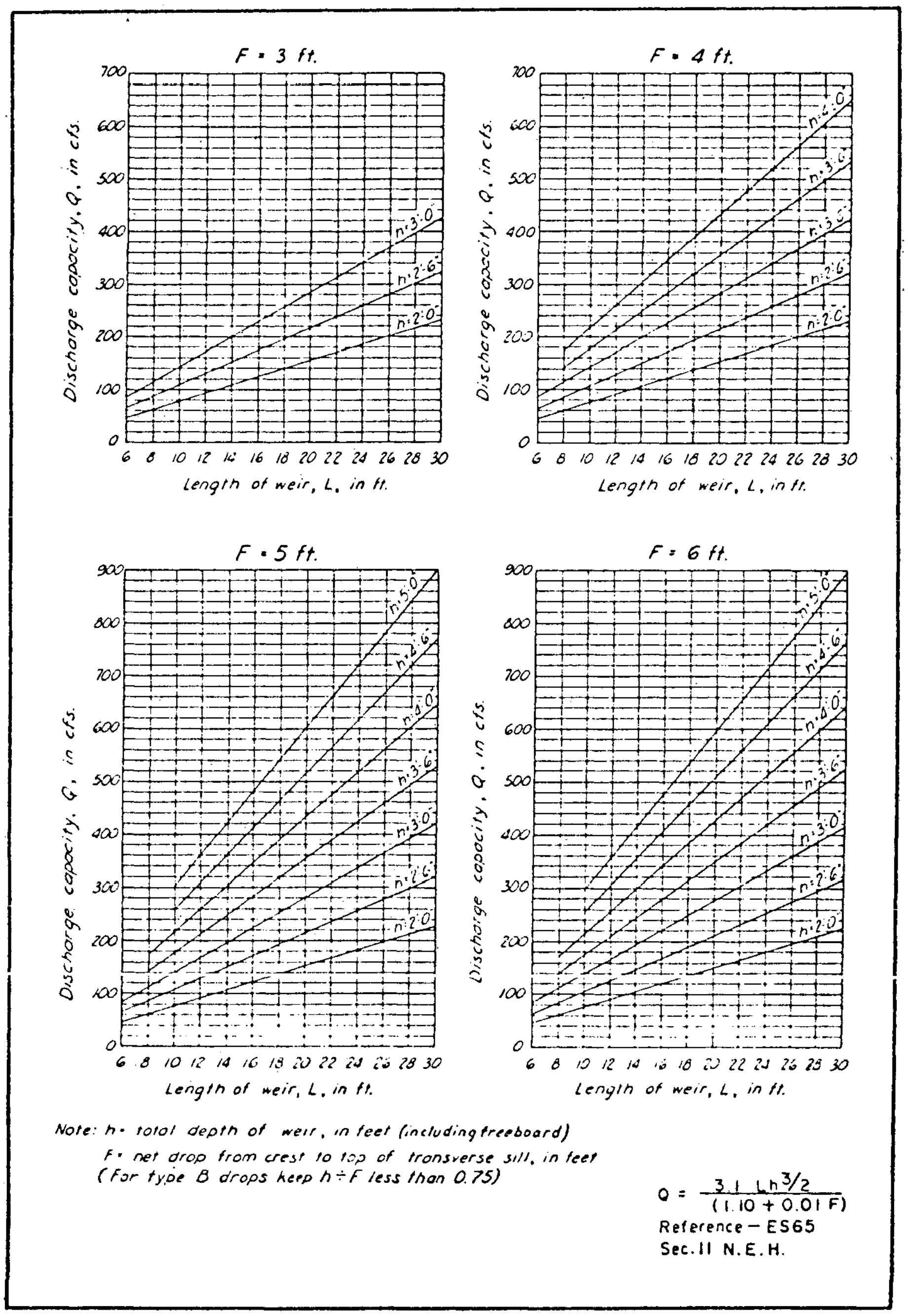
Figures 4-8 and 4-9 are complete plans for low head box drop structures. Their main function is grade reduction in waterways insofar as Alabama is concerned. Weir length can be determined from Figure 4-7. Estimating quantities are shown in the figures.

In many cases drainage must be installed in drop structures as a guard against development of flotation forces during non-flow periods. Adding 5 percent to other costs should approximate this cost.

Chute Spillway

The chute spillway offers particular advantages in being able to carry very large flow volumes and in not being highly subject to

Figure 4-7. Weir Capacity for Straight Drop Spillways.



Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 4-11.

Table 4-5. Standard Plans: Series "B" Reinforced Concrete Drop Spillways Schedule Showing Drawing Number, Cubic Yards of Concrete, and Pounds of Reinforcing Steel.

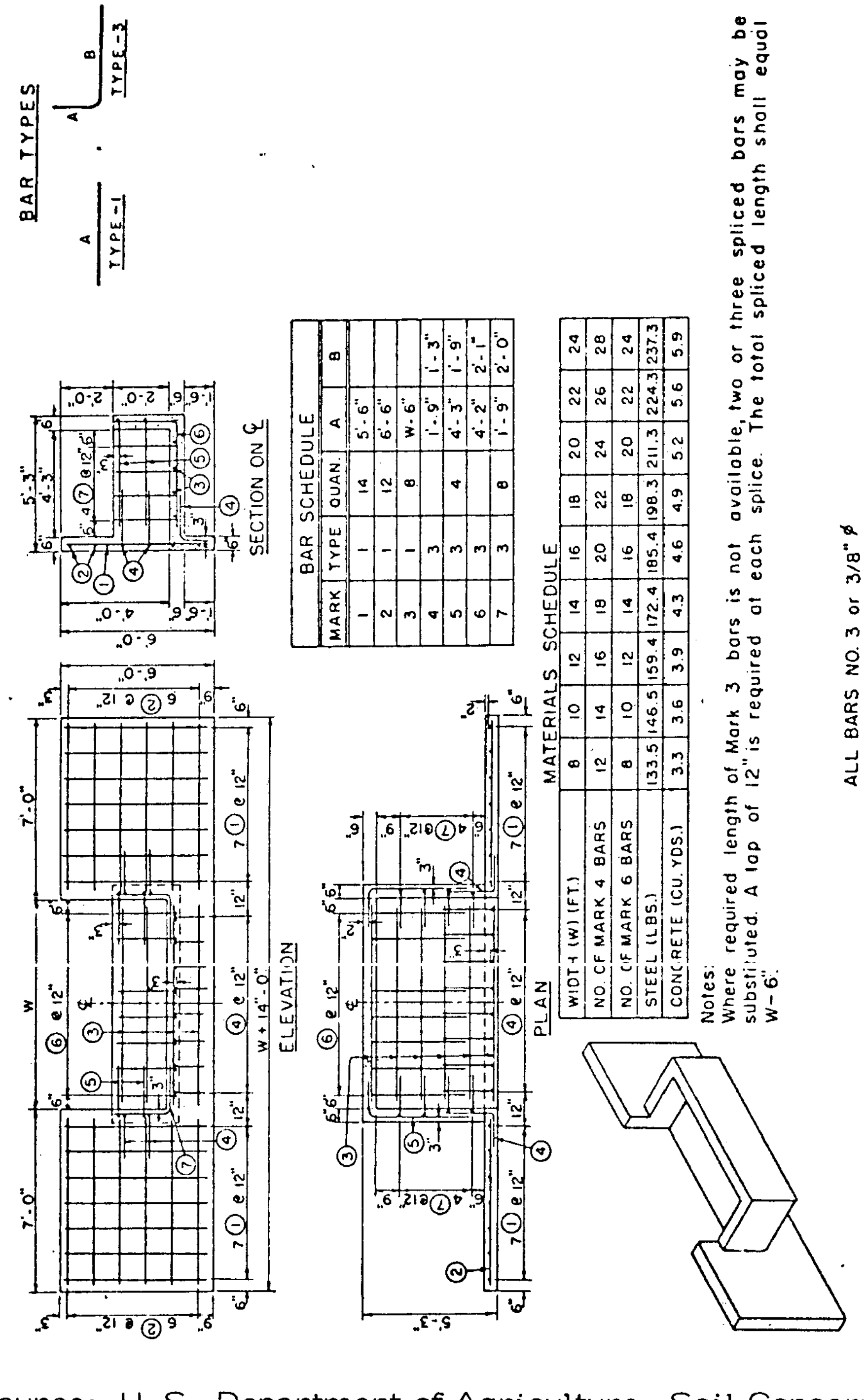
F	h \ L	6	8	10	12	14	16	18	20	22	24	26	28	30
5	2-6	2051-6B 19.96 1400.47	2051-8B 21.52 1591.56	2051-10B 22.66 1655.79	2051-12B 24.13 1757.67	2051-14B 25.47 1862.85	2051-16B 26.81 1947.69	2051-18B 26.15 2148.56	2051-20B 29.49 2206.65	2051-22B 30.83 2376.90	2051-24B 32.17 2456.50	2051-26B 33.51 2548.91	2051-28B 34.84 2708.46	2051-30B 36.18 2923.96
	3-0	2052-6B 24.36 1975.61	2052-8B 25.78 2167.93	2052-10B 27.20 2416.75	2052-12B 28.79 2313.39	2052-14B 30.21 2464.78	2052-16B 31.63 2559.55	2052-18B 33.05 2720.13	2052-20B 34.46 2850.56	2052-22B 35.88 2906.63	2052-24B 37.30 3117.16	2052-26B 38.72 3230.65	2052-28B 40.14 3368.08	2052-30B 41.56 3531.59
	3-6										2053-24B 43.00 3437.55	2053-26B 44.56 3635.43	2053-28B 46.05 3812.61	2053-30B 47.55 4023.02
6	2-6	2061-6B 21.08 1601.43	2061-8B 22.50 1767.24	2061-10B 23.92 2034.92	2061-12B 25.49 1975.92	2061-14B 26.91 2092.83	2061-16B 28.33 2206.57	2061-18B 29.75 2433.87	2061-20B 31.17 2532.35	2061-22B 32.59 2734.61	2061-24B 34.01 2830.05	2061-26B 35.43 2906.33	2061-28B 36.85 3167.85	2061-30B 38.27 3405.80
	3-0	2062-6B 25.64 2103.37	2062-8B 27.14 2283.59	2062-10B 28.64 2592.72	2062-12B 30.35 2464.05	2062-14B 31.85 2626.73	2062-16B 33.33 2814.70	2062-18B 34.83 3025.67	2062-20B 36.33 3111.19	2062-22B 37.83 3309.60	2062-24B 39.33 3465.35	2062-26B 40.83 3622.56	2062-28B 42.33 3817.93	2062-30B 43.83 4035.17
	3-6										2063-24B 45.77 3961.17	2063-26B 47.36 4173.51	2063-28B 48.96 4424.57	2063-30B 50.55 4660.84
	4-0	2064-6B* 36.70 3294.66	2064-8B 38.38 3553.83	2064-10B 40.05 3645.15	2064-12B 42.02 3626.74	2064-14B 43.69 4033.21	2064-16B 45.36 4166.49	2064-18B 47.04 4454.74	2064-20B 48.71 4544.66	2064-22B 50.38 4602.44	2064-24B 52.05 4667.94	2064-26B 53.73 5392.81	2064-28B 55.40 5511.74	2064-30B 57.07 5798.13
7	2-6	2071-6B 24.15 1770.40	2071-8B 25.64 1942.20	2071-10B 27.15 2281.97	2071-12B 28.61 2133.03	2071-14B 30.33 2291.06	2071-16B 31.64 2494.10	2071-18B 33.35 2650.02	2071-20B 34.85 2795.37	2071-22B 36.37 2965.80				
	3-0	2072-6B 27.21 2305.64	2072-8B 28.61 2554.60	2072-10B 30.41 2971.44	2072-12B 32.20 2768.75	2072-14B 33.79 2985.86	2072-16B 35.39 3106.17	2072-18B 36.98 3296.11	2072-20B 38.58 3456.51	2072-22B 40.17 3683.76	2072-24B 41.77 3934.24	2072-26B 43.37 4104.64	2072-28B 44.96 4308.07	2072-30B 46.56 4638.52
	3-6										2073-24B 47.94 4606.39	2073-26B 49.62 4881.46	2073-28B 51.29 5103.44	2073-30B 52.97 5389.75
	4-0	2074-6B* 38.72 3517.19	2074-8B 40.49 3818.79	2074-10B 42.26 4322.54	2074-12B 44.34 4060.57	2074-14B 46.11 4324.97	2074-16B 47.88 4435.01	2074-18B 49.65 4679.42	2074-20B 51.41 4941.73	2074-22B 53.15 5356.99	2074-24B 54.95 5614.07	2074-26B 56.72 5842.55	2074-28B 58.49 6118.87	2074-30B 60.25 6465.29
	4-6											2075-26B 64.60 6608.62	2075-28B 66.44 6902.07	2075-30B 68.29 7270.07
	5-0	2076-6B* 51.66 5756.46	2076-8B* 53.52 6063.63	2076-10B 55.45 6506.82	2076-12B 57.83 6374.43	2076-14B 59.76 6650.05	2076-16B 61.69 6866.52	2076-18B 63.61 7137.51	2076-20B 65.54 7383.82	2076-22B 67.47 7831.14	2076-24B 69.39 8221.24	2076-26B 72.01 7976.59	2076-28B 73.93 8195.88	2076-30B 75.86 8441.24
8	2-6	2081-6B 28.52 2286.72	2081-8B 30.11 2160.93	2081-10B 31.70 2694.57										
	3-0	2082-6B 30.00 2606.59	2082-8B 31.67 2933.42	2082-10B 33.35 3393.86	2082-12B 35.22 3166.00	2082-14B 36.90 3418.33	2082-16B 38.57 3621.84	2082-18B 40.24 3842.53	2082-20B 41.92 4035.89	2082-22B 43.59 4266.66	2082-24B 45.26 4796.48	2082-26B 46.93 4646.29	2082-28B 49.45 4947.78	2082-30B 51.12 4600.91
	3-6								2083-20B 46.92 4835.15	2083-22B 48.69 5148.66	2083-24B 50.45 5314.69	2083-26B 52.22 5673.64	2083-28B 54.83 5596.68	2083-30B 56.59 5568.93
	4-0	2084-6B* 40.29 3942.57	2084-8B 42.14 4290.39	2084-10B 43.99 4427.26	2084-12B 46.17 4568.02	2084-14B 48.02 4859.58	2084-16B 49.87 5001.22	2084-18B 51.71 5440.11	2084-20B 53.56 5692.84	2084-22B 55.41 5976.66	2084-24B 57.26 6443.37	2084-26B 59.96 6131.76	2084-28B 61.81 6355.72	2084-30B 63.66 6667.19
	4-6											2085-26B 67.43 7648.51	2085-28B 69.36 8050.62	2085-30B 71.28 8319.20
	5-0	2086-6B* 54.03 6732.94	2086-8B* 56.05 7051.00	2086-10B 58.07 7196.94	2086-12B 60.57 7400.45	2086-14B 62.59 7637.53	2086-16B 64.61 7941.71	2086-18B 66.63 8353.59	2086-20B 68.66 8708.75	2086-22B 71.61 8487.16	2086-24B 73.64 8603.10	2086-26B 75.66 9273.94	2086-28B 77.68 9698.10	2086-30B 79.70 10130.08
9	2-6	2091-6B [illegible] 2656.37	2091-8B [illegible] 3156.72	2091-10B [illegible] 3239.05										
	3-0	2092-6B 35.02 3165.85	2092-8B 36.79 3375.92	2092-10B 38.77 3596.27	2092-12B 40.54 3653.91	2092-14B 42.31 4148.74	2092-16B 44.08 4398.52	2092-18B 45.85 4672.12	2092-20B 47.62 4965.56	2092-22B 50.50 4669.20	2092-24B 52.27 4859.04	2092-26B 54.03 5168.69	2092-28B 55.80 5478.50	2092-30B 57.57 5825.59
	3-6	2093-6B* 36.91 3065.64	2093-8B 38.76 4022.45	2093-10B 40.61 4343.10	2093-12B 42.74 4405.55	2093-14B 44.59 4659.65	2093-16B 46.44 4949.25	2093-18B 48.29 5268.60	2093-20B 50.13 5628.76	2093-22B 53.09 5279.76	2093-24B 54.94 5526.79	2093-26B 56.79 5916.74	2093-28B 58.64 6187.66	2093-30B 60.48 6559.76
	4-0	2094-6B* 41.81 4376.42	2094-8B 43.74 4718.70	2094-10B 45.66 5193.83	2094-12B 47.95 5067.65	2094-14B 49.88 5355.07	2094-16B 51.81 5644.16	2094-18B 53.74 6034.57	2094-20B 56.60 5792.65	2094-22B 58.73 6148.78	2094-24B 60.66 6327.49	2094-26B 62.59 6602.44	2094-28B 64.52 7022.40	2094-30B 66.46 7406.17
	4-6											2095-26B 70.76 8571.17	2095-28B 72.79 8944.40	2095-30B 74.81 9317.86
	5-0	2096-6B* 55.92 7504.69	2096-8B* 58.02 7844.56	2096-10B 60.12 8505.86	2096-12B 62.72 8456.26	2096-14B 64.83 8639.17	2096-16B 66.93 9017.95	2096-18B 69.03 9355.63	2096-20B 71.27 9176.51	2096-22B 74.37 9509.15	2096-24B 76.48 9827.44	2096-26B 78.58 10311.98	2096-28B 80.69 10693.95	2096-30B 82.79 10790.97

(1) Notes: Drawing No., cu. yds of concrete, and lbs. of reinforcing steel are listed vertically in order for each size. Each drawing number shall be prefixed with the letters E. S.

(2) *The ratio of L ÷ h is less than 2.0 for these values. Correction for hydraulic losses due to end contractions must be considered in the solution of the weir formula, for discharge capacity, before these drop spillways can be applied.

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices, (1969), p. 6-12.

Figure 4-8. Standard Plan For a Reinforced Concrete Toe Wall With 2' - 0" Overfall Drop Spillway.



BAR SCHEDULE				
MARK	TYPE	QUAN.	A	B
1	1	14	5'-6"	
2	1	12	6'-6"	
3	1	8	W-6"	
4	3		1'-9"	1'-3"
5	3	4	4'-3"	1'-9"
6	3		4'-2"	2'-1"
7	3	8	1'-9"	2'-0"

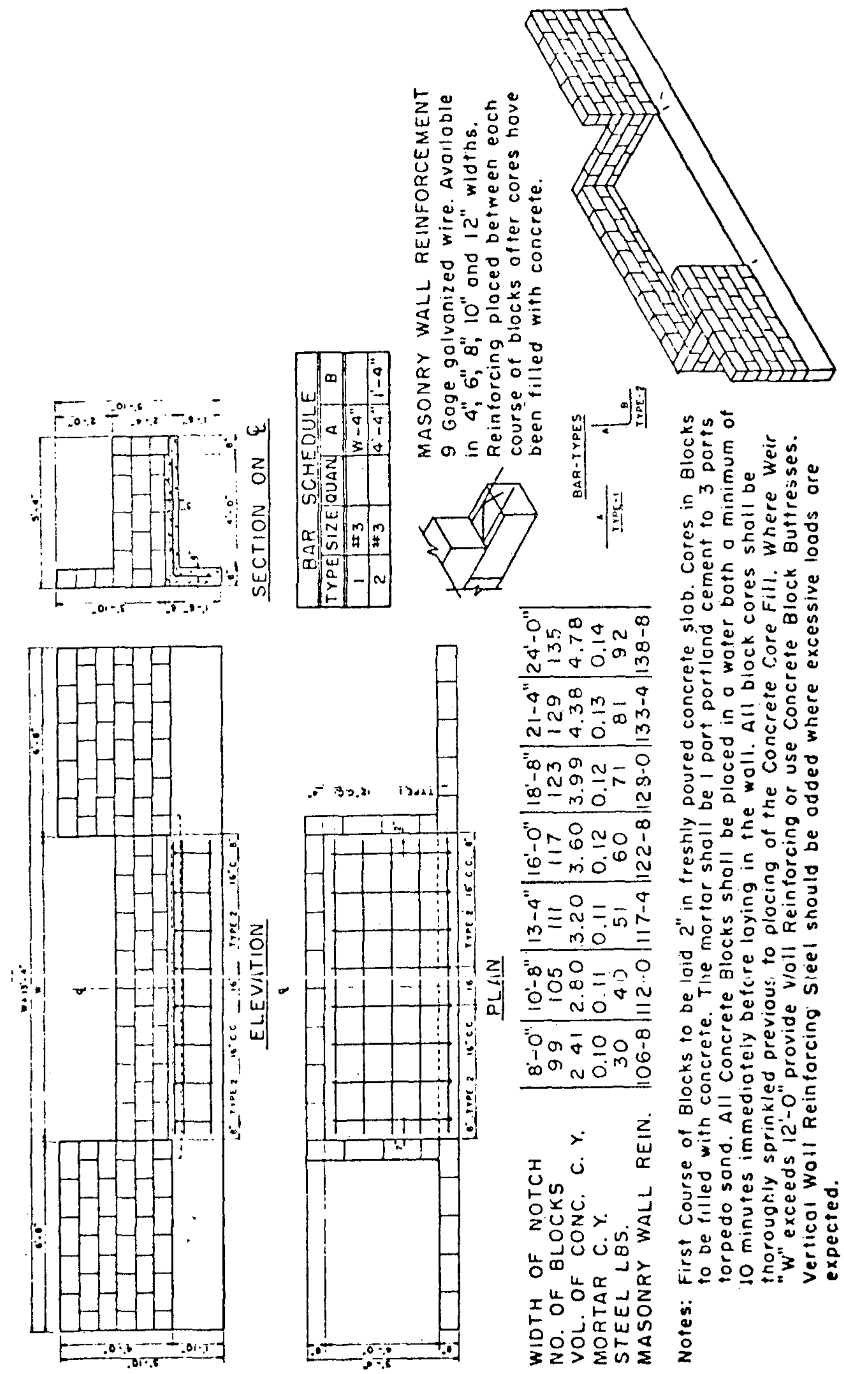
MATERIALS SCHEDULE

WIDTH (W) (FT.)	8	10	12	14	16	18	20	22	24
NO. OF MARK 4 BARS	12	14	16	18	20	22	24	26	28
NO. OF MARK 6 BARS	8	10	12	14	16	18	20	22	24
STEEL (LBS.)	133.5	146.5	159.4	172.4	185.4	198.3	211.3	224.3	237.3
CONCRETE (CU. YDS.)	3.3	3.6	3.9	4.3	4.6	4.9	5.2	5.6	5.9

Notes:
Where required length of Mark 3 bars is not available, two or three spliced bars may be substituted. A lap of 12" is required at each splice. The total spliced length shall equal W-6".

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual For Conservation Practices (1969), p. 6-13.

Figure 4-9. Standard Plan for a Concrete Block Toe Wall Drop Spillway with 1' - 10" Overfall.



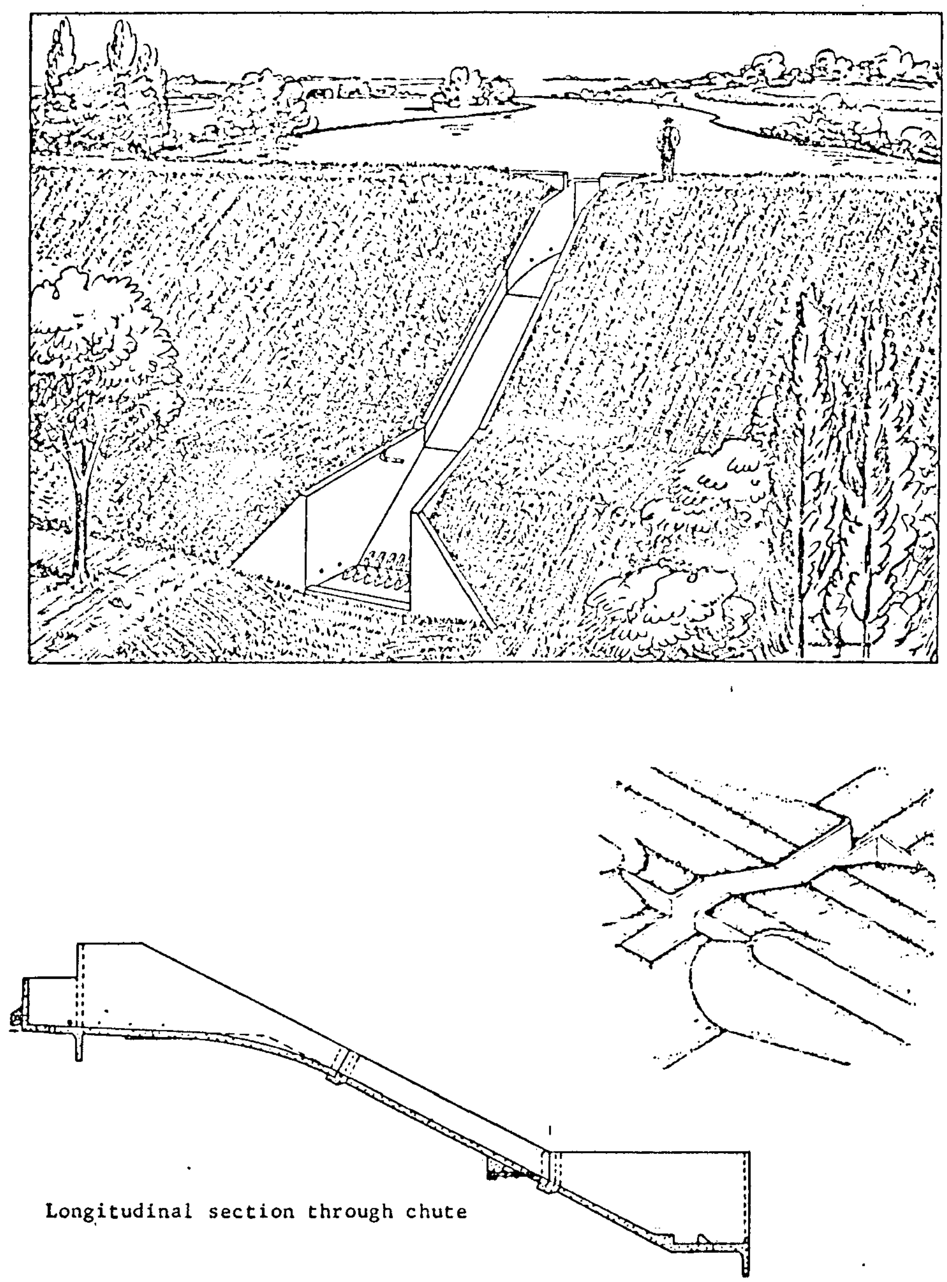
BAR SCHEDULE				
TYPE	SIZE	QUAN	A	B
1	#3		W-4"	
2	#3		4'-4"	1'-4"

WIDTH OF NOTCH	8'-0"	10'-8"	13-4"	16'-0"	18'-8"	21-4"	24'-0"
NO. OF BLOCKS	99	105	111	117	123	129	135
VOL. OF CONC. C. Y.	2.41	2.80	3.20	3.60	3.99	4.38	4.78
MORTAR C. Y.	0.10	0.11	0.11	0.12	0.12	0.13	0.14
STEEL LBS.	30	40	51	60	71	81	92
MASONRY WALL REIN.	106-8	112-0	117-4	122-8	128-0	133-4	138-8

Notes: First Course of Blocks to be laid 2" in freshly poured concrete slab. Cores in Blocks to be filled with concrete. The mortar shall be 1 part portland cement to 3 parts torpedo sand. All Concrete Blocks shall be placed in a water bath a minimum of 10 minutes immediately before laying in the wall. All block cores shall be thoroughly sprinkled previous to placing of the Concrete Core Fill. Where Weir "W" exceeds 12'-0" provide Wall Reinforcing or use Concrete Block Buttresses. Vertical Wall Reinforcing Steel should be added where excessive loads are expected.

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices, (1969), p. 6-14.

Figure 4-10. Reinforced Concrete Chute Spillway.



Source: U.S. Department of Agriculture Soil Conservation Service, Engineering Field Manual for Conservation Practices, (1969), p. 6-24.

clogging. One type of chute is illustrated by Figure 4-10.

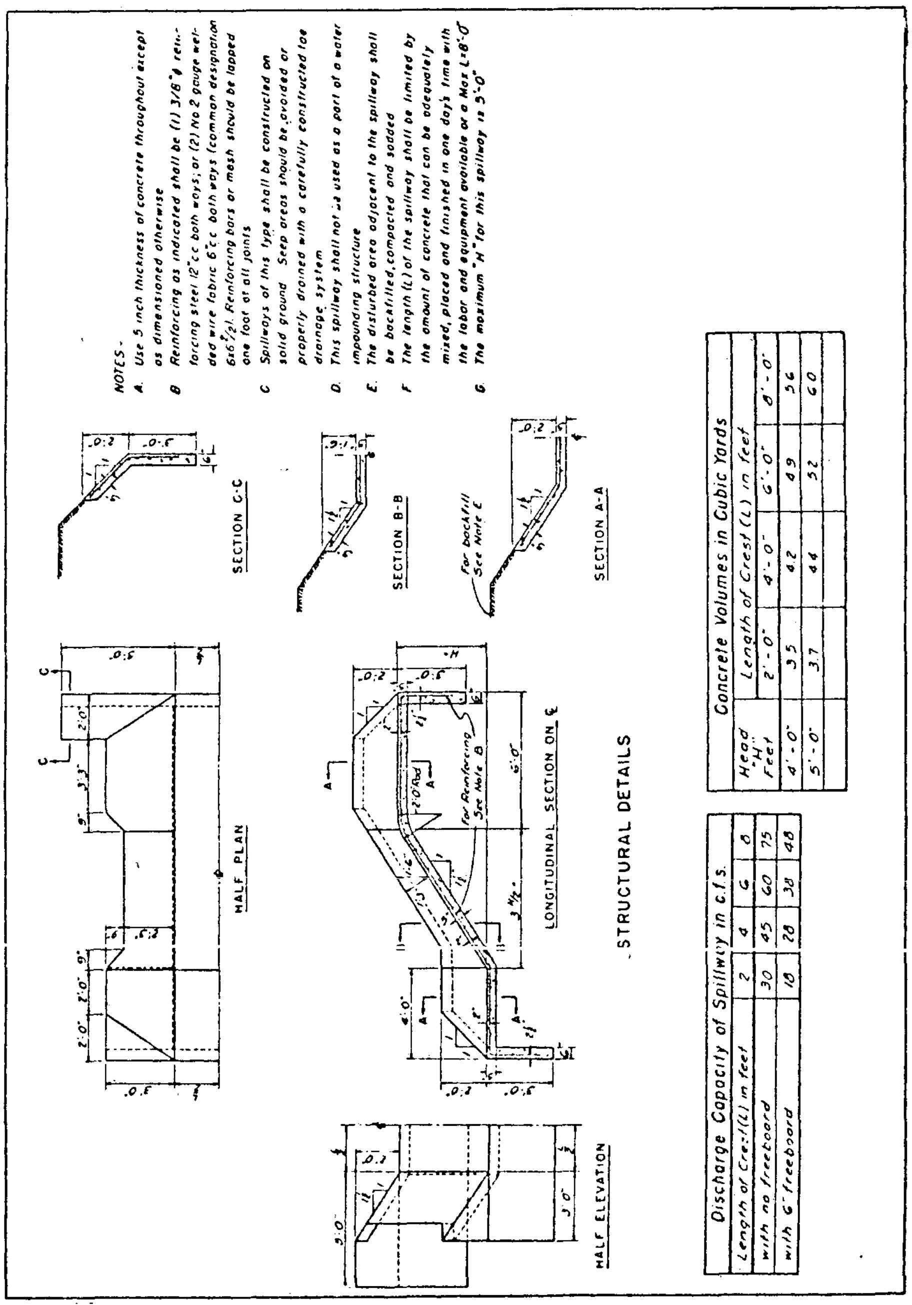
The major limitations are: need for stable outlet conditions, danger of damage from settlement, and damage from burrowing rodents.

Design of chutes requires the services of one with specialized knowledge. The Soil Conservation Service's National Engineering Handbook Section 14 contains valuable information on proportioning chute spillways (5).

Figures 4-11 and 4-12 show details of a relatively simple concrete chute. It is called a formless chute, because intricate forming is not required. This standardized design has application over a narrow range of head and discharge conditions. It has little application in the severe gully areas of Alabama. It is a viable competitor for "side inlet" application on stream channel work in moderately erosion-resistant material. Minor seepage protection would be required for this use.

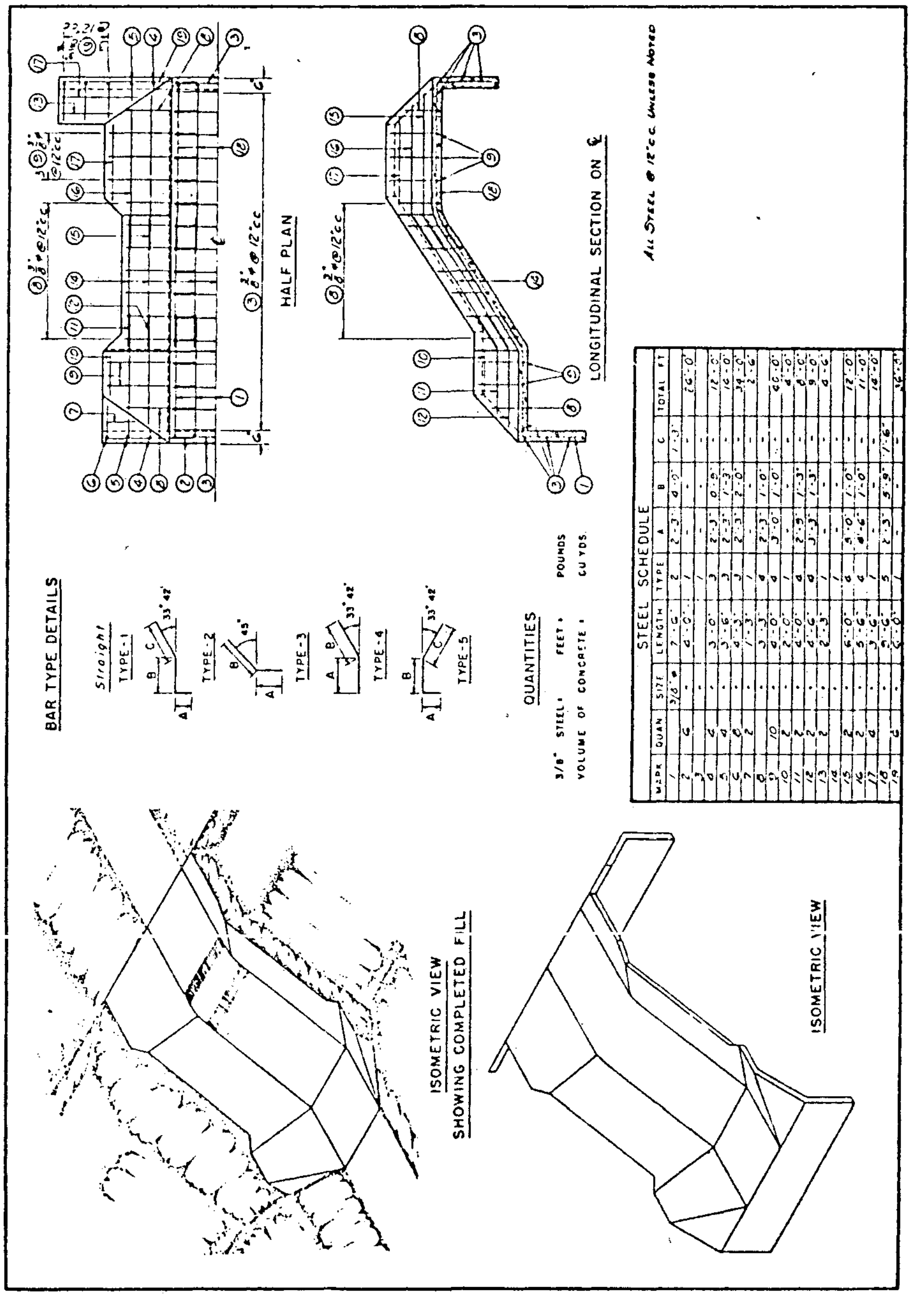
Virtually all the concrete plants in the state have a 3000 p.s.i. concrete mix approved by the highway department for bridges and culverts. Reducing the water content of this mix by 3 to 6 gallons per cubic yard will produce concrete stiff enough to stand up during placement on the slopes of this chute.

Figure 4–11. Typical Standard Plan for Low Head Formless Concrete Chute.



Source: U.S. Department of Agriculture Soil Conservation Service, Engineering Field Manual for Conservation Practices, (1969), p. 6–26 to 6–27.

Figure 4-12. Typical Standard Plan for Low Head Formless Concrete Chute.



Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices. (1969), p. 6-27.

Drop Inlet and Hood Inlet Spillways

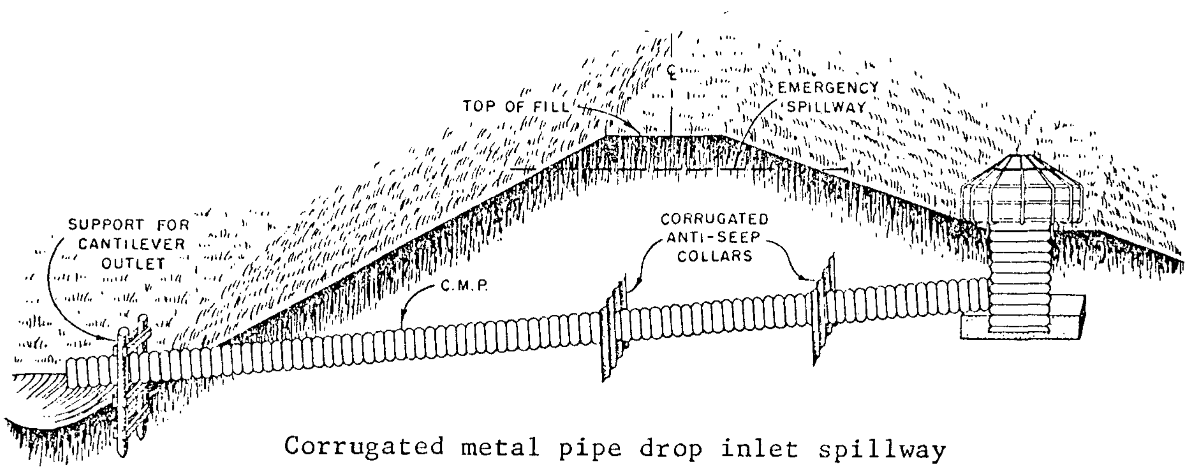
The adaptations of these two measure types are very much alike. They become hydraulically efficient with increasing heads, reducing construction materials required per unit volume of flow. It is also easier to provide deep foundations for their outlets, giving them a very clear advantage where outlet conditions are unstable or uncertain. Figures 4-13 and 4-14 illustrate typical installations of these inlet types.

The major limitation of these spillway inlets is their susceptibility to clogging by debris. Drop inlets are extremely hazardous in urban areas, unless special steps are taken to prevent curious children (and others) from falling into the inlet.

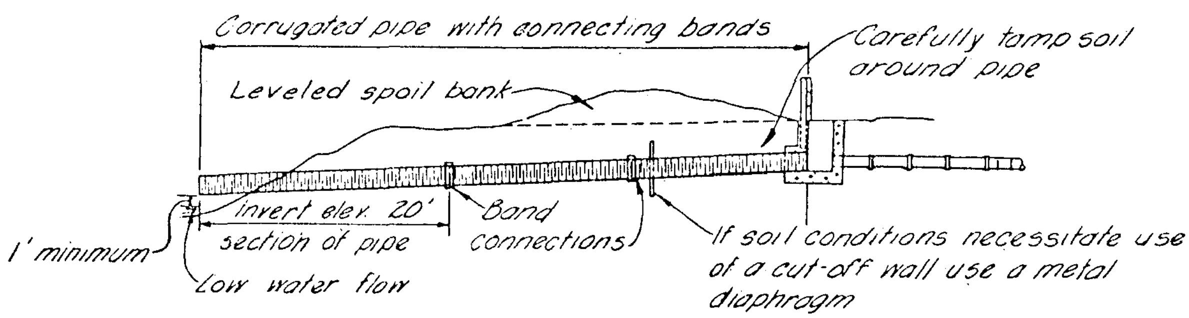
Once they are primed and flowing full, these two spillway types carry about the same volume of water for a given hydraulic head and outlet size. The hood inlet would be later priming than a drop inlet, if their inlet and outlets were at identical elevations. This difference is more significant in larger conduit sizes. The problem is largely overcome by placing the hood inlet in a shallow box inlet as illustrated by Figure 4-15. The illustrated inlet is practical without modification for 24 and 30-inch spillways. Larger concrete block inlets are considered unsatisfactory by the writer.

It is always desirable to install a pipe spillway on original

Figure 4-13. Examples of Drop Inlet Spillways.



Corrugated metal pipe drop inlet spillway



Drop inlet spillway used to lower surface water into a channel

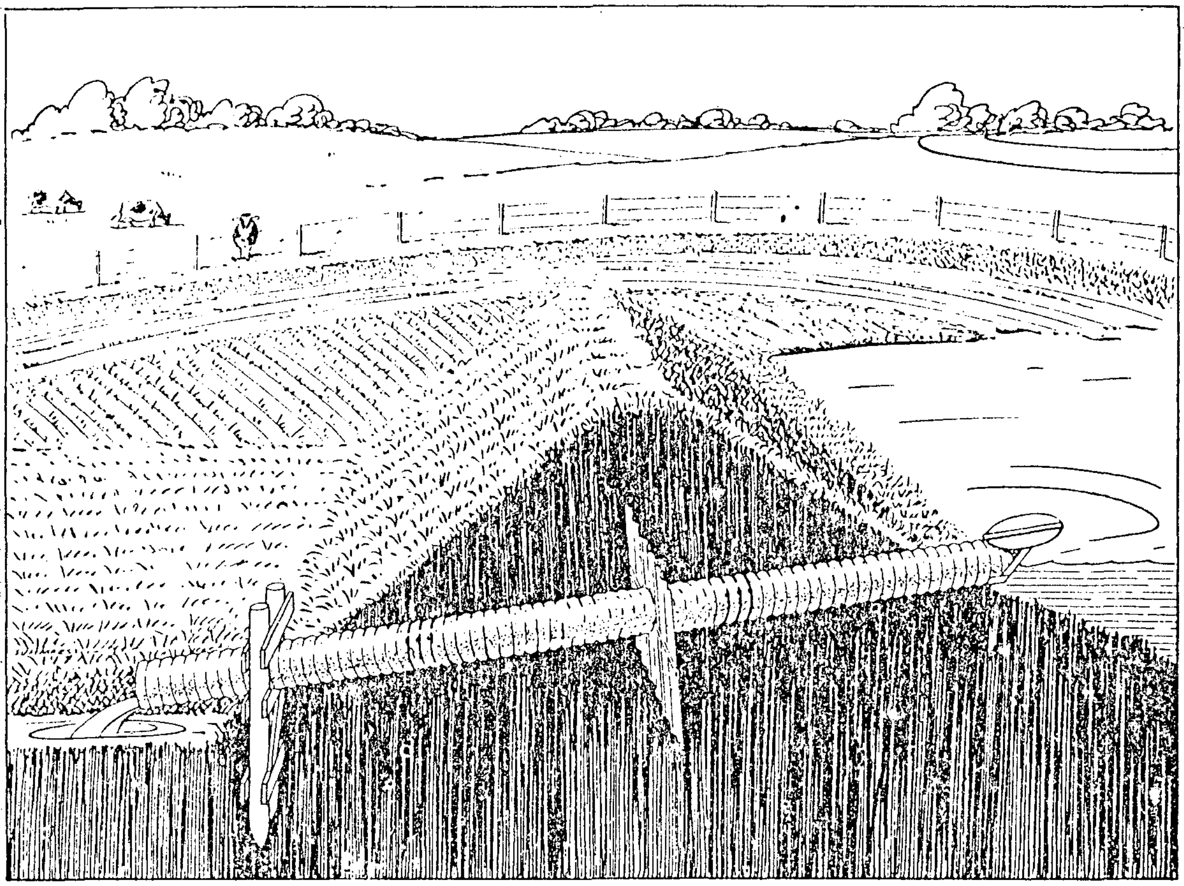
Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Measures (1969), p. 6-32.

ground rather than on fill. This often controls selection between the drop inlet and the hood inlet.

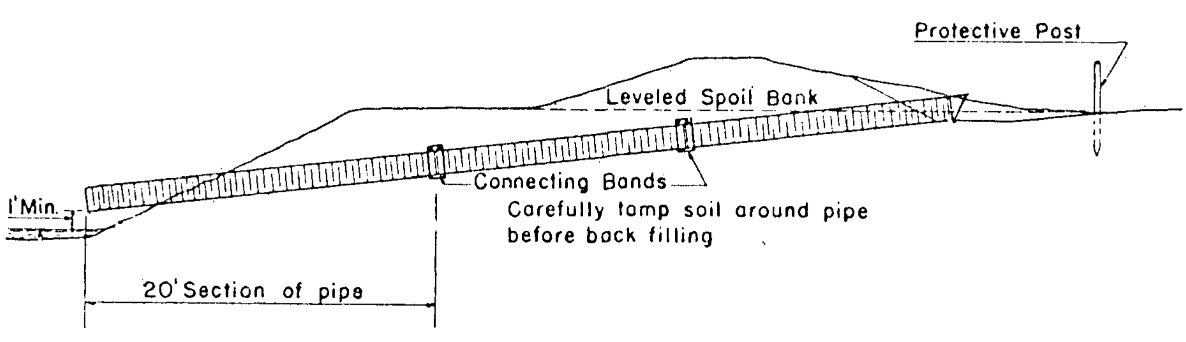
Design

Large sized closed conduit structures and especially those with reinforced concrete inlets or other similar features require specialized design knowledge.

Figure 4-14. Hood Inlet Spillways.



Metal pipe with hood inlet



Hood inlet used to lower surface water into a channel

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Measures (1969), p. 6-47.

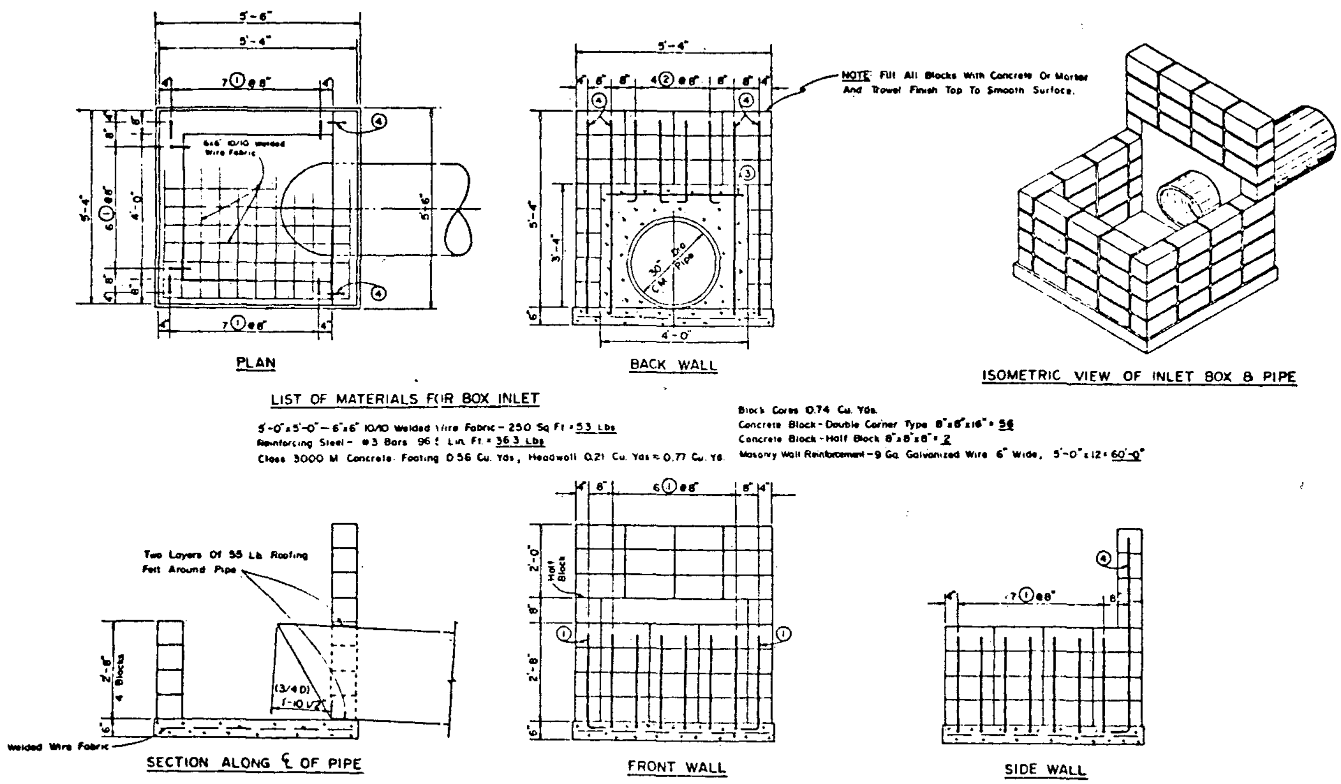


Figure 4-15. Hood Inlet In A Shallow Box Inlet.

While they are not so durable as concrete nor as hydraulically efficient, corrugated metal and smooth steel pipe are the chief materials used in this category of structures. This section contains tables and other data for completely designing this type of construction.

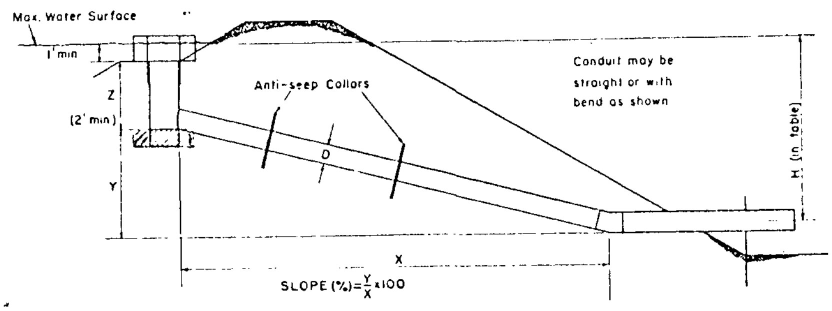
In planning gully control measures, life expectancy should not be overlooked. Concrete pressure pipe offers much greater life expectancy than corrugated metal. It costs more but carries more water in any given size. Installation cost is more than for corrugated metal. Relative life is at least 2 to 1 and probably 4 to 1 in severe applications (25 years versus 50 to 100 years).

Sizing Inlets and Conduits

Tables 4-6 through 4-8 and Figure 4-16 are used to size the pipe and inlet for drop inlet structures. Enter Tables 4-6 through 4-8 with the design discharge and available hydraulic head. The head (H) is measured vertically from the planned design water surface elevation to the planned elevation of the center of the outlet pipe. Figure 4-16, which includes an example, is used to select a proper riser size to efficiently prime the outlet pipe and to determine the required priming head (h). Pertinent limitations are noted on the chart.

Tables 4-9 through 4-11 are used to size pipe for a hooded

Table 4-6. Capacity Chart For 8 Inch and 12 Inch C. M. Pipe Drop Inlet Spillway.



CROSS SECTION OF DAM ON ℄ OF PIPE SPILLWAY

Height of Riser

1. Enter Table No. 1 with the planned conduit slope. (See view above and use next largest whole number for entering table.)
2. From Table No. 1 obtain value for discharge (Q) for planned conduit size.
3. If Q obtained from Table No. 1 is:
   (a) greater than Q shown in Table No. 2 (for the design head, conduit length and conduit size), a riser height (Z) of 5D is required to provide full pipe flow.
   (b) equal to or less than that Q shown in Table No. 2 a riser height (Z) less than 5D can be used. (minimum height = 2.0')

TABLE NO. 1

Slope %	Discharge (Q) cfs 8" Pipe	12" Pipe
5	1.4	4.1
6	1.5	4.5
7	1.7	4.9
8	1.8	5.2
9	1.9	5.5
10	2.0	5.8
11	2.1	6.1
12	2.2	6.4
13	2.3	6.6
14	2.4	6.9
15	2.4	7.1
16	2.5	7.3
[illegible]	[illegible]	[illegible]
18	2.7	7.8
19	2.7	8.0
20	2.6	8.2
21	2.9	8.4
22	2.9	8.6
23	3.0	8.8
24	3.1	9.0
25	3.1	9.2
26	3.2	9.3
27	3.3	9.5
28	3.3	9.7
29	3.4	9.9
30	3.4	10.1

TABLE NO. 2

CAPACITY TABLE FOR PIPE INLETS

Head H Feet	8" Conduit-18" Riser For Pipe Lengths of: 50'	70'	90'	12" Conduit-18" Riser For Pipe Lengths of: 50'	70'	90'
5	1.8	1.6	1.4	5.0	4.4	4.0
6	2.0	1.7	1.5	5.5	4.9	4.4
7	2.1	1.9	1.7	6.0	5.3	4.7
8	2.3	2.0	1.8	6.4	5.6	5.1
9	2.4	2.1	1.9	6.8	6.0	5.4
10	2.6	2.2	2.0	7.1	6.3	5.7
11	2.7	2.3	2.1	7.5	6.6	6.0
12	2.8	2.4	2.2	7.8	6.9	6.2
13	2.9	2.5	2.3	8.1	7.2	6.4
14	3.0	2.6	2.3	8.4	7.4	6.7
15	3.1	2.7	2.4	6.7	7.7	6.9
16	3.2	2.8	2.5	9.0	7.9	7.2
17	3.3	2.9	2.6	9.3	8.2	7.4
18	3.4	3.0	2.7	9.6	8.4	7.6
19	3.5	3.1	2.7	9.8	8.7	7.8
20	3.6	3.1	2.8	10.1	8.9	8.0

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices, (1969) p. 6-40.

Table 4-7. Pipe Flow Chart For Corrugated Metal Pipe Drop Inlet Spillway.

PIPE FLOW CHART (Full flow assumed)

For Corrugated Metal Pipe Inlet $K_e + K_b = 1.0$ and 70 feet of Corrugated Metal Pipe Conduit $n = 0.025$. Note correction factors for other pipe lengths.

Dia. / H	12"	15"	18"	21"	24"	30"	36"	42"
2	2.84	4.92	7.73	11.30	15.60	26.60	40.77	58.12
3	3.48	6.03	9.47	13.84	19.10	32.58	49.93	71.19
4	4.02	6.96	10.94	15.98	22.06	37.62	57.66	82.20
5	4.49	7.78	12.23	17.87	24.66	42.06	64.46	91.90
6	4.92	8.52	13.40	19.57	27.01	46.07	70.60	100.65
7	5.32	9.21	14.47	21.14	29.19	49.77	76.28	108.75
8	5.68	9.84	15.47	22.60	31.19	53.19	81.53	116.23
9	6.03	10.44	16.41	23.97	33.09	56.43	86.49	123.30
10	6.36	11.00	17.30	25.26	34.88	59.48	91.16	129.96
11	6.67	11.54	18.14	26.50	36.59	62.39	95.63	136.33
12	6.96	12.05	18.95	27.68	38.21	65.16	99.87	142.37
13	7.25	12.55	19.72	28.81	39.77	67.83	103.96	148.21
14	7.52	13.02	20.47	29.90	41.27	70.39	107.88	153.80
15	7.78	13.48	21.19	30.95	42.72	72.85	111.66	159.18
16	8.04	13.92	21.88	31.96	44.12	75.24	115.32	164.40
17	8.29	14.35	22.55	32.94	45.48	77.55	118.87	169.46
18	8.53	14.77	23.21	33.90	46.80	79.81	122.33	174.39
19	8.76	15.17	23.84	34.83	48.08	81.99	125.67	179.15
20	8.99	15.56	24.46	35.73	49.33	84.12	128.93	183.80
21	9.21	15.95	25.07	36.62	50.55	86.21	132.13	188.36
22	9.43	16.32	25.65	37.47	51.73	88.22	135.21	192.76
23	9.64	16.69	26.23	38.32	52.90	90.21	138.27	197.12
24	9.85	17.05	26.80	39.14	54.04	92.15	141.24	201.35
25	10.05	17.40	27.35	39.95	55.15	94.05	144.15	205.50
L	Correction Factors For Other Pipe Lengths							
40	1.23	1.22	1.20	1.19	1.16	1.14	1.13	1.11
50	1.14	1.13	1.12	1.11	1.10	1.09	1.08	1.07
60	1.07	1.06	1.06	1.05	1.05	1.04	1.04	1.03
70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
80	0.95	0.95	0.95	0.96	0.96	0.96	0.97	0.97
90	0.90	0.91	0.91	0.92	0.92	0.93	0.94	0.94
100	0.86	0.87	0.88	0.89	0.89	0.90	0.91	0.92

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 6-41.

Table 4-8. Pipe Flow Chart for Concrete Pipe Drop Inlet Spillway.

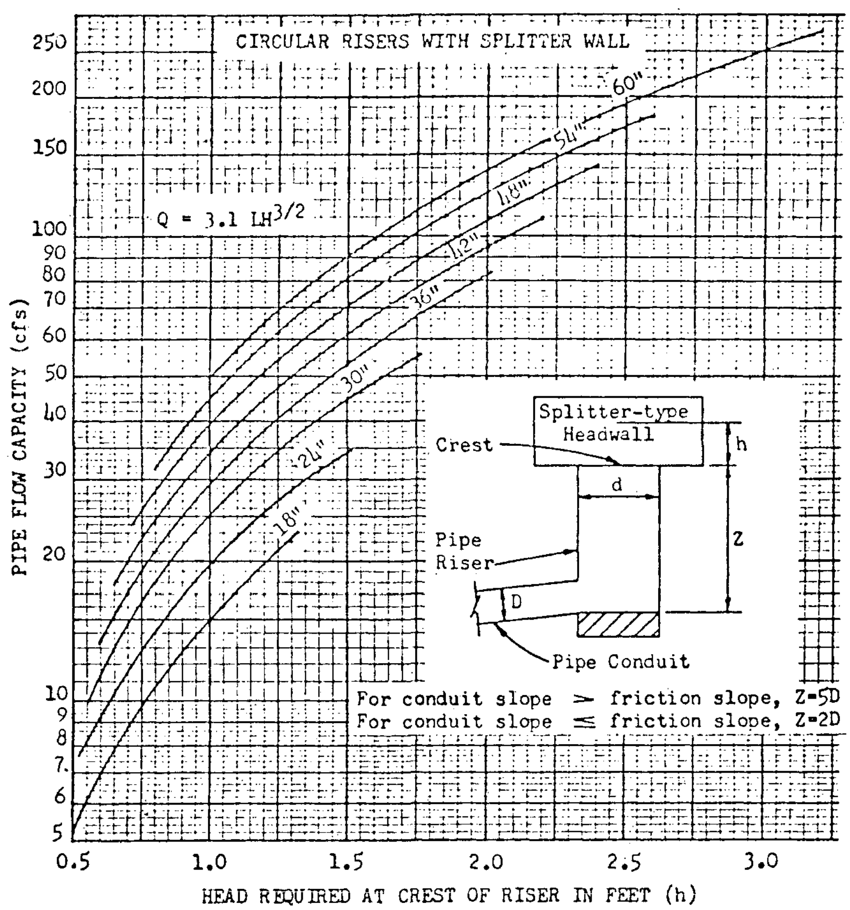
PIPE FLOW CHART (Full Pipe flow assumed)

For R/C Drop Inlet, $K_e + K_b = 0.65$ with 70 feet of R/C conduit, n = .013. Note correction factors for other pipe lengths.

H \ Dia.	12"	15"	18"	21"	24"	30"	36"	42"
2	4.54	8.01	11.74	16.60	22.44	36.74	54.65	76.02
3	5.56	9.81	14.39	20.33	27.49	45.00	66.94	93.11
4	6.42	11.33	16.61	23.48	31.74	51.96	77.30	107.52
5	7.18	12.66	18.57	26.25	35.49	58.09	86.42	120.21
6	7.87	13.86	20.34	28.75	38.87	63.63	94.65	131.66
7	8.50	14.98	21.98	31.06	41.99	68.74	102.27	142.25
8	9.08	16.01	23.49	33.20	44.88	73.47	109.30	152.03
9	9.64	17.00	24.92	35.22	47.61	77.94	115.95	161.28
10	10.16	17.91	26.26	37.12	50.18	82.15	122.21	169.99
11	10.65	18.78	27 55	38.94	52.64	86.18	128.20	178.32
12	11.13	19.62	28.77	40.67	54.97	89.99	133.88	186.22
13	11.58	20.42	29.95	42.33	57.23	93.68	139.37	193.86
14	12.01	21.18	31.07	43.93	59 37	97.19	144.59	201.12
15	12.44	21.93	32.17	45.47	61.46	100.62	149.69	208.21
16	12.85	22.65	33.22	46.96	63.48	103.92	154.60	215.04
17	13.24	23.35	34.24	48.40	65.43	107.12	159.35	221.65
18	13.63	24.03	35.24	49.81	67.34	110.23	163.99	228.10
19	14.00	24.68	36.21	51.17	69.18	113.25	168.48	234.34
20	14.36	25.32	37.14	52.50	70.97	116.18	172.84	240.41
21	14.72	25.95	38.07	53.80	72.73	119.07	177.13	246.38
22	15.06	26.56	38.96	55.06	74.43	121.85	181.27	252.13
23	15.40	27.16	39.84	56.31	76.11	124.60	185.36	257.83
24	15.73	27.74	40.69	57.51	77.75	127.28	189.35	263.37
25	16.06	28.32	41.53	58.70	79.35	129.90	193.25	268.80
L	Correction Factors For Other Pipe Lengths							
40	1.15	1.13	1.11	1.09	1.08	1.06	1.06	1.05
50	1.09	1.08	1.07	1.06	1.05	1.04	1.04	1.03
60	1.04	1.04	1.04	1.03	1.03	1.02	1.02	1.02
70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
80	0.96	0.96	0.97	0.97	0.98	0.98	0.98	0.99
90	0.93	0.94	0.94	0.95	0.95	0.96	0.97	0.97
100	0.90	0.91	0.92	0.93	0.93	0.95	0.95	0.96

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 6-42.

Figure 4-16. Chart for Determining Inlet Proportions and Required Head Over Inlet.



Inlet Proportions	
Pipe Conduit (D)-in.	Pipe Riser (d)-in.
8-12	18
15	21
18	24
21	30
24	30
30	36
36	48
42	54
48	60

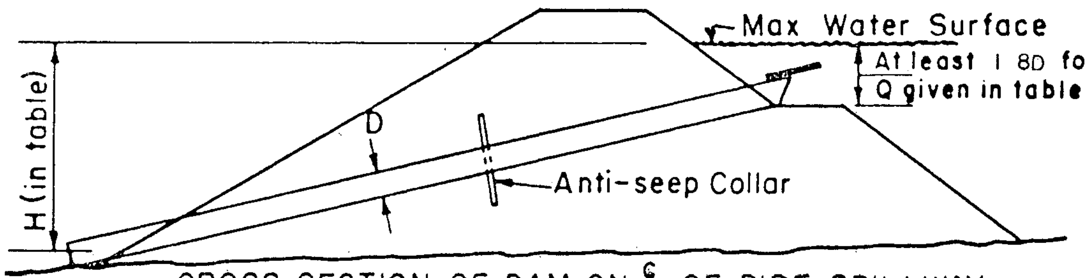
Pipe Drop Inlet Spillway Design:

For a given Q and H, refer to Figure 4-17 or 4-18 for conduit size. Then determine the riser diameter (d) from the Inlet Proportions table on this figure. Next, refer to the above curves, using the conduit capacity and riser diameter and find the head (h) required above the crest of the riser. The height of the riser should not be less than 5D - h, except as noted in the above sketch.

Example: Given: CMP; Q = 20 cfs; H = 14 ft., h max 1.0 ft.; L = 70 ft. From Figure 4-17 find conduit size (D) = 18 inches. From Inlet Proportions table, riser size = 24 inches. Head (h) required for Q = 20 and d = 24 is 1.0 foot.

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices, (1969), p. 6-43.

Table 4-9. Capacity Chart for 8 and 12 Inch C.M. Pipe Hood Inlet Spillway.



CROSS SECTION OF DAM ON ℄ OF PIPE SPILLWAY

CAPACITY TABLE OF HOODED INLET IN C.F.S. FOR VARYING HEADS						
Head H	8" DIAMETER PIPE For Pipe Lengths of: 50'	70'	90'	12" DIAMETER PIPE For Pipe Lengths of: 50'	70'	90'
5	1.8	1.6	1.4	5.0	4.4	4.0
6	2.0	1.7	1.5	5.5	4.8	4.4
7	2.1	1.9	1.7	6.0	5.2	4.7
8	2.3	2.0	1.8	6.3	5.6	5.0
9	2.4	2.1	1.9	6.7	5.9	5.4
10	2.6	2.2	2.0	7.1	6.2	5.6
11	2.7	2.3	2.1	7.4	6.5	5.9
12	2.8	2.4	2.2	7.8	6.8	6.2
13	2.9	2.5	2.3	8.1	7.1	6.4
14	3.0	2.6	2.3	8.4	7.4	6.7
15	3.1	2.7	2.4	8.7	7.6	6.9
16	3.2	2.8	2.5	9.0	7.9	7.1
17	3.3	2.9	2.6	9.2	8.1	7.3
18	3.4	3.0	2.7	9.5	8.4	7.6
19	3.5	3.0	2.7	9.8	8.6	7.8
20	3.6	3.1	3.0	10.0	8.8	8.0

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 6-49.

Table 4-10. Pipe Flow Chart for Corrugated Metal Pipe Hood Inlet Spillway.

PIPE FLOW CHART (Full flow assumed)

For Hooded Inlet K_e = 1.08 and 70 feet of Corrugated Metal Pipe Conduit, n = 0.025.
Note corrections for other pipe lengths.

H \ Dia.	12"	15"	18"	21"	24"	30"	36"	42"
2	2.79	4.89	7.72	11.16	15.48	26.31	40.28	57.42
3	3.41	5.99	9.46	13.67	18.97	32.32	49.34	70.34
4	3.94	6.92	10.92	15.78	21.90	37.32	56.98	81.22
5	4.40	7.74	12.21	17.64	24.48	41.72	63.70	90.80
6	4.82	8.47	13.37	19.32	26.82	45.70	69.77	99.45
7	5.21	9.16	14.45	20.88	28.97	49.37	75.38	107.45
8	5.57	9.78	15.44	22.31	30.97	52.77	80.57	114.85
9	5.91	10.38	16.38	23.61	32.85	55.98	85.47	121.83
10	6.23	10.94	17.26	24.95	34.62	59.00	90.09	128.41
11	6.53	11.48	18.11	26.17	36.32	61.90	94.50	134.70
12	6.82	11.99	18.91	27.33	37.93	64.64	98.69	140.67
13	7.10	12.48	19.69	28.45	39.49	67.29	102.73	146.44
14	7.37	12.95	20.43	29.52	40.97	69.83	106.61	151.96
15	7.63	13.40	21.15	30.56	42.41	72.27	110.34	157.28
16	7.88	13.84	21.84	31.56	43.80	74.64	113.96	162.44
17	8.13	14.27	22.51	32.53	45.15	76.94	117.46	167.44
18	8.36	14.68	23.17	33.48	46.46	79.17	120.88	172.31
19	8.59	15.08	23.80	34.39	47.73	81.34	124.19	177.02
20	8.81	15.47	24.42	35.28	48.97	83.45	127.41	181.61
21	9.03	15.86	25.02	36.16	50.18	85.52	130.57	186.12
22	9.24	16.23	25.61	37.00	51.36	87.52	133.62	190.46
23	9.45	16.59	26.19	37.84	52.52	89.49	136.64	194.77
24	9.65	16.95	26.69	38.65	53.64	91.42	139.57	198.95
25	9.85	17.30	27 30	39.45	54.75	93.30	142.45	203.05
L	Correction Factors For Other Lengths							
40	1.23	1.21	1.19	1.18	1.16	1.13	1.12	1.10
50	1.14	1.13	1.12	1.11	1.10	1.09	1.08	1.07
60	1.06	1.06	1.05	1.05	1.04	1.04	1.04	1.03
70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
80	0.95	0.95	0.95	0.96	0.96	0.96	0.97	0.97
90	0.90	0.91	0.91	0.92	0.92	0.93	0.94	0.94
100	0.86	0.87	0.88	0.89	0.89	0.90	0.91	0.92

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices, (1969), p. 6-50.

Table 4-11. Pipe Flow Chart for Smooth Pipe Hood Inlet Spillway.

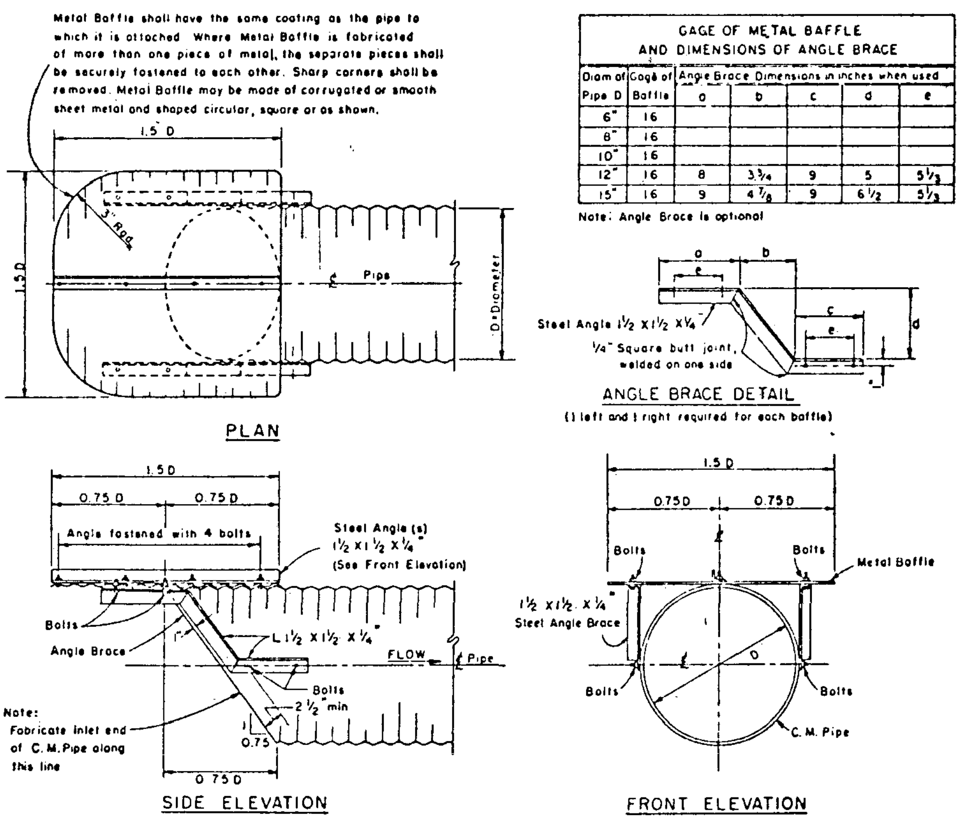
PIPE FLOW CHART (Full flow assumed)

For Hooded Inlet K_e = 1.08 and 70 feet of smooth pipe conduit, n = 0.010. Note corrections for other lengths.

Dia. / H	10"	12"	14"	15"	18"	21"
2	3.20	4.85	6.85	7.99	11.92	16.64
3	3.92	5.94	8.38	9.79	14.60	20.39
4	4.53	6.85	9.68	11.31	16.86	23.54
5	5.06	7.66	10.82	12.64	18.85	26.32
6	5.54	8.39	11.86	13.84	20.64	28.83
7	5.99	9.07	12.81	14.96	22.30	31.15
8	6.40	9.69	13.69	15.99	23.84	33.29
9	6.79	10.28	14.52	16.96	25.29	35.31
10	7.16	10.84	15.31	17.87	26.65	37.22
11	7.51	11.36	16.05	18.74	27.95	39.03
12	7.83	11.87	16.77	19.58	29.20	40.77
13	8.16	12.36	17.46	20.41	30.39	42.45
14	8.47	12.82	18.11	21.15	31.54	44.05
15	8.77	13.27	18.75	21.89	32.64	45.59
16	9.06	13.71	19.36	22.61	33.72	47.08
17	9.33	14.13	19.96	23.31	34.75	48.53
18	9.61	14.54	20.54	29.99	35.76	49.94
19	9.87	14.94	21.10	24.64	36.74	51.31
20	10.12	15.33	21.65	25.28	37.69	52.64
21	10.38	15.71	22.19	25.91	38.63	53.95
22	10.62	16.07	22.70	26.51	39.53	55.21
23	10.86	16.44	23.24	27.11	40.42	56.45
24	11.09	16.79	23.72	27.69	41.29	57.67
25	11.32	17.14	24.21	28.26	42.14	58.86
L	Correction Factors for Other Lengths					
40	1.11	1.09	1.08	1.08	1.06	1.05
50	1.07	1.06	1.05	1.05	1.04	1.03
60	1.03	1.03	1.02	1.02	1.02	1.02
70	1.00	1.00	1.00	1.00	1.00	1.00
80	0.97	0.97	0.98	0.98	0.98	0.98
90	0.95	0.95	0.96	0.96	0.96	0.97
100	0.93	0.93	0.94	0.94	0.95	0.96

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 6-51.

Figure 4-17. Details of a Typical Hood Inlet and Baffle for 6 to 15 Inch Diameter Corrugated Metal Pipe.



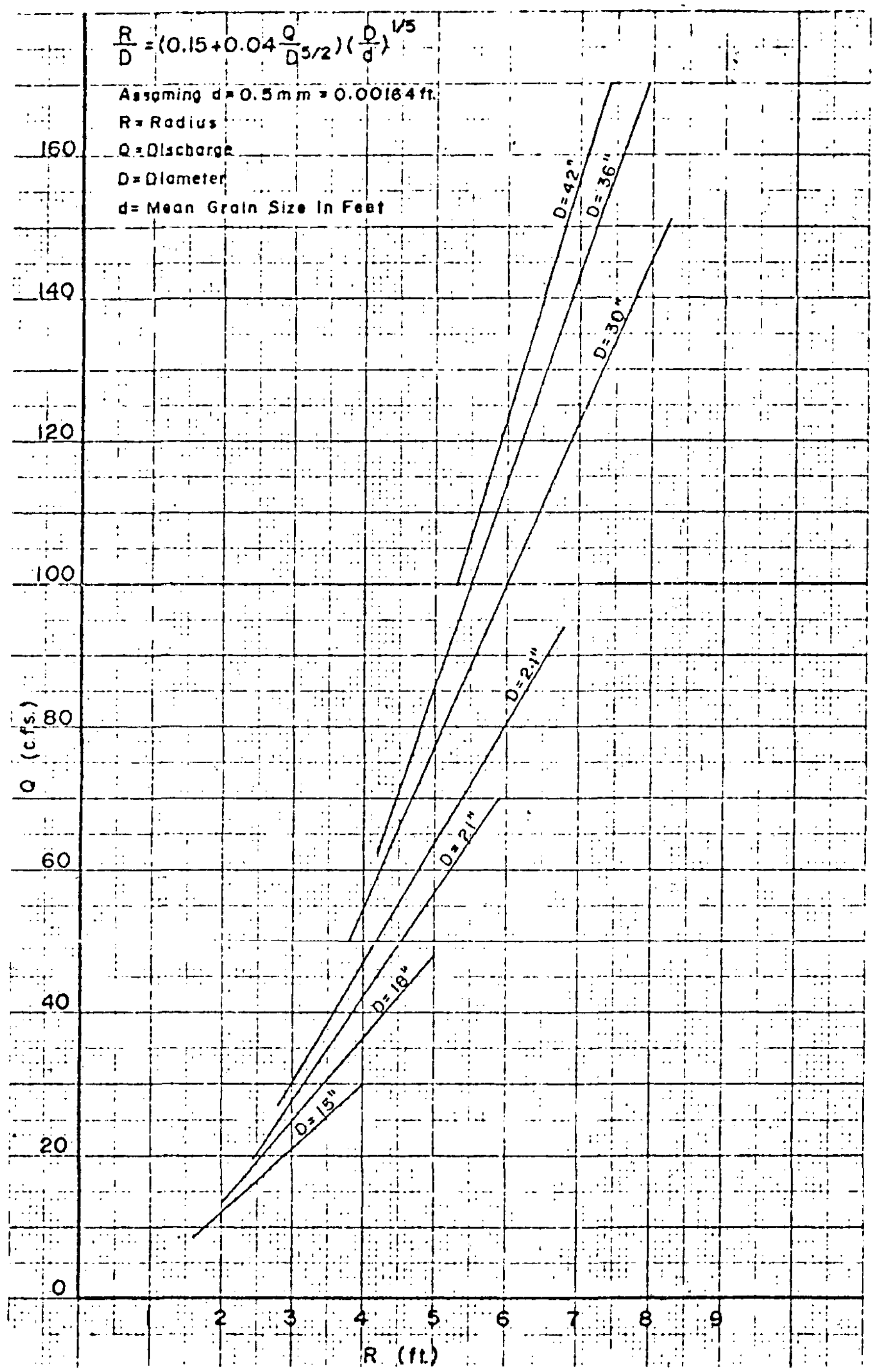
GAGE OF METAL BAFFLE AND DIMENSIONS OF ANGLE BRACE						
Diam of Pipe D	Gage of Baffle	Angle Brace Dimensions in inches when used				
		a	b	c	d	e
6"	16					
8"	16					
10"	16					
12"	16	8	3¾	9	5	5⅓
15"	16	9	4⅞	9	6½	5⅓

Note: Angle Brace is optional

Notes:
All bolts shall be ⅜" X 1½" with nut and split washers
All holes for bolts shall be drilled 7/16" diameter.
All nuts, bolts and washers shall be galvanized, cadmium plated, or stainless steel
All cuts shall be saw or shear cuts.
Holes in the angle brace shall be spaced and located to match corrugations in pipe and baffle.
Steel angles shall be galvanized.
All galvanizing damaged by cutting, drilling or welding shall be repaired by painting with two (2) coats of zinc dust-zinc oxide primer.

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices, (1969), p. 6-52.

Figure 4-18. Chart To Compute Radius For Scour Hole, For Hood Inlets And Pipe Drops.



Source: U.S. Department of Agriculture, Soil Conservation Service, Alabama Engineering Field Manual for Conservation Practices (1972), Auburn, p. 6-8.

inlet spillway. Notation is essentially as described above and is illustrated in Table 4-9. These tables assume the presence of an anti-vortex baffle on the slanted, or hooded, inlet pipe. It is also assumed that the design water surface elevation is at least sufficient to provide a head of 1.8 times the pipe diameter above the invert of the pipe at the inlet. This may be satisfied, partially or wholly, with a shallow box inlet. Figure 4-15 illustrates a variation of this approach. Figure 4-17 illustrates a typical hood inlet baffle installation.

Inlet Protection

It is necessary to place a scour apron around inlets to provent scour and undermining. Four feet of 4-inch thick, temperature-rein forced concrete in all directions from the inlet (or invert for hooded inlet) is the minimum acceptable. This concrete apron is usually considered as sufficing for protection against seepage along the conduit for conduits no longer than 40 feet. When design discharge exceeds 50 c.f.s., the apron dimension should equal R from Figure 4-18.

Antiseep Collars and Couplings

The predominant cause of failure of earth dams with pipe spillways is seepage along the pipe. Antiseep collars hopefully reduce this hazard. A sufficient number of collars is usually provided to increase the distance line of seepage along the conduit by 15 percent. The projection of these diaphragms is normally two feet except in very small structures. Most are metal with a watertight connection to the pipe (4-6). Figure 4-19 illustrates two variations of metal antiseep collars.

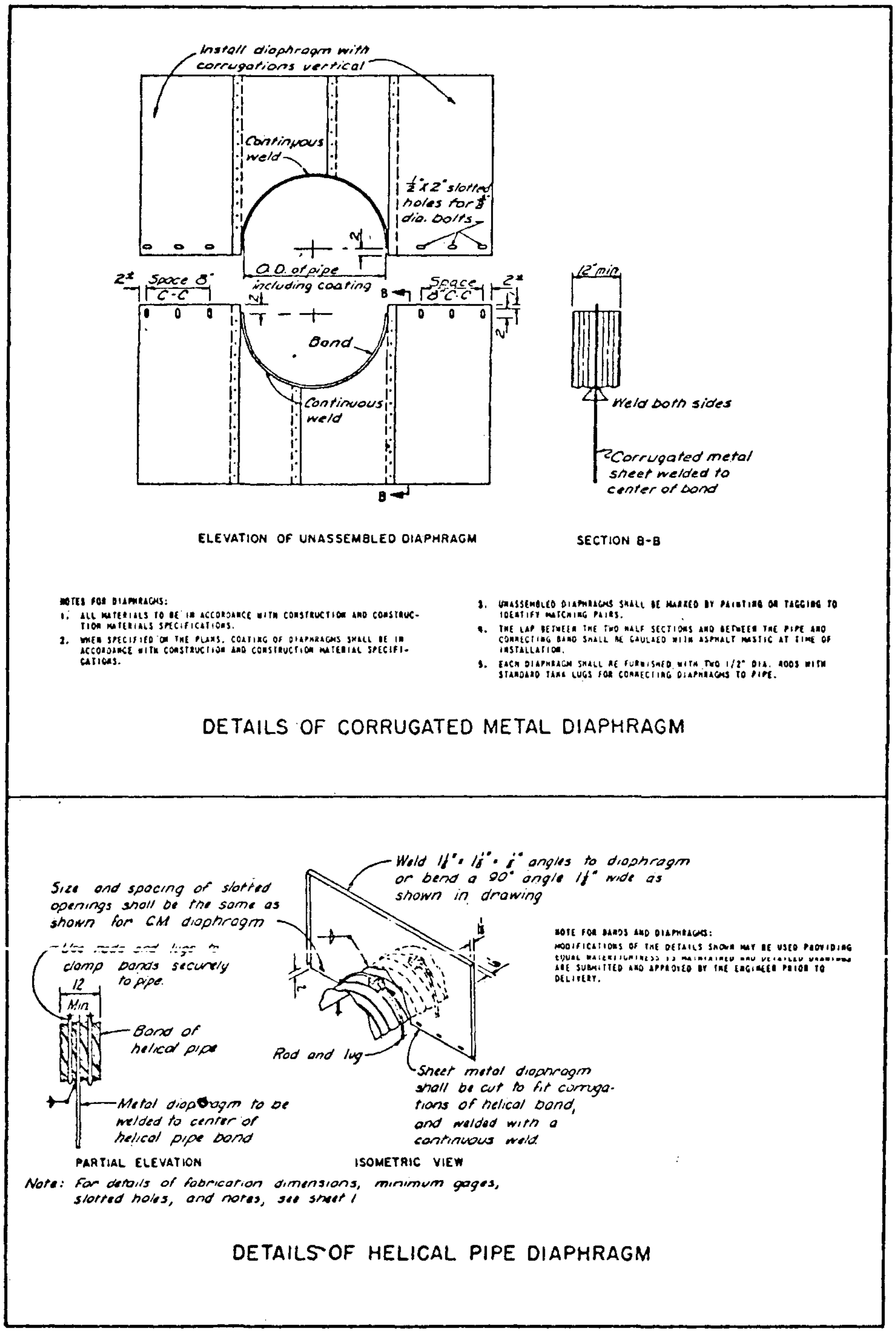
Connecting Bands

Very strong connecting bands are needed to hold pipe joints together when they are used in a cantilever application (unsupported end). Adverse experiences with several types of connections which were developed for helical pipe have led to the conclusion that only the "rod and lug" type of connection, illustrated in Figure 4-20, applies sufficient pressure to hold the pipes together in long-term operation. The bands should be at least two feet long with 4 to 6 rod connectors. Four may be used through a pipe diameter of 36 inches except at the outlet joint. The connecting band nearest the outlet should be of the same gauge metal as the pipe. When bituminous coating is used, all joints, and especially the downstream one, need to be retightened after 12 to 24 hours.

Trash Rack

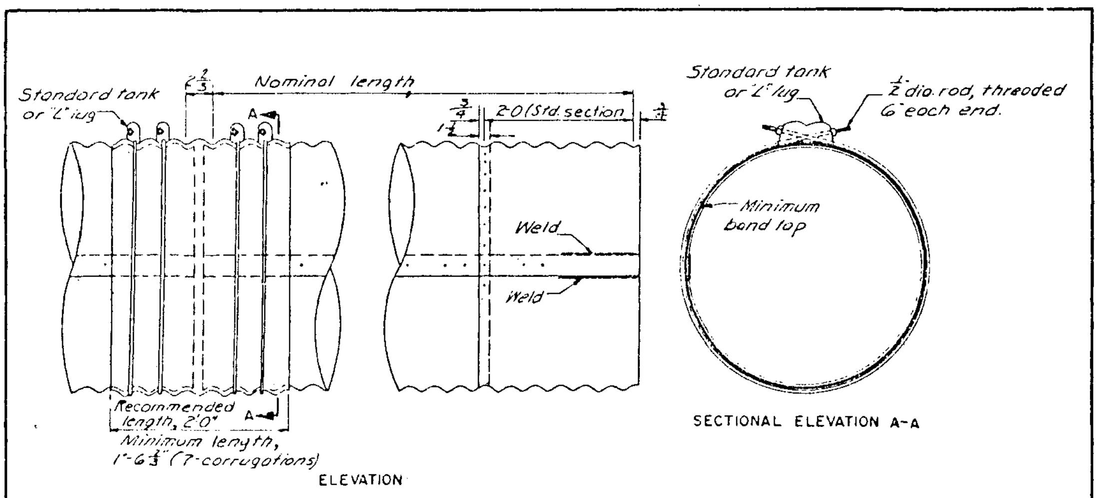
A trash rack or other means of trash exclusion is needed in

Figure 4-19. Appurtenances for Metal Pipe Drop Inlets.



Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 6-37.

Figure 4-20. Appurtenances For Metal Pipe Drop Inlets.



DETAILS OF WATERTIGHT COUPLING BAND FOR C.M. PIPE

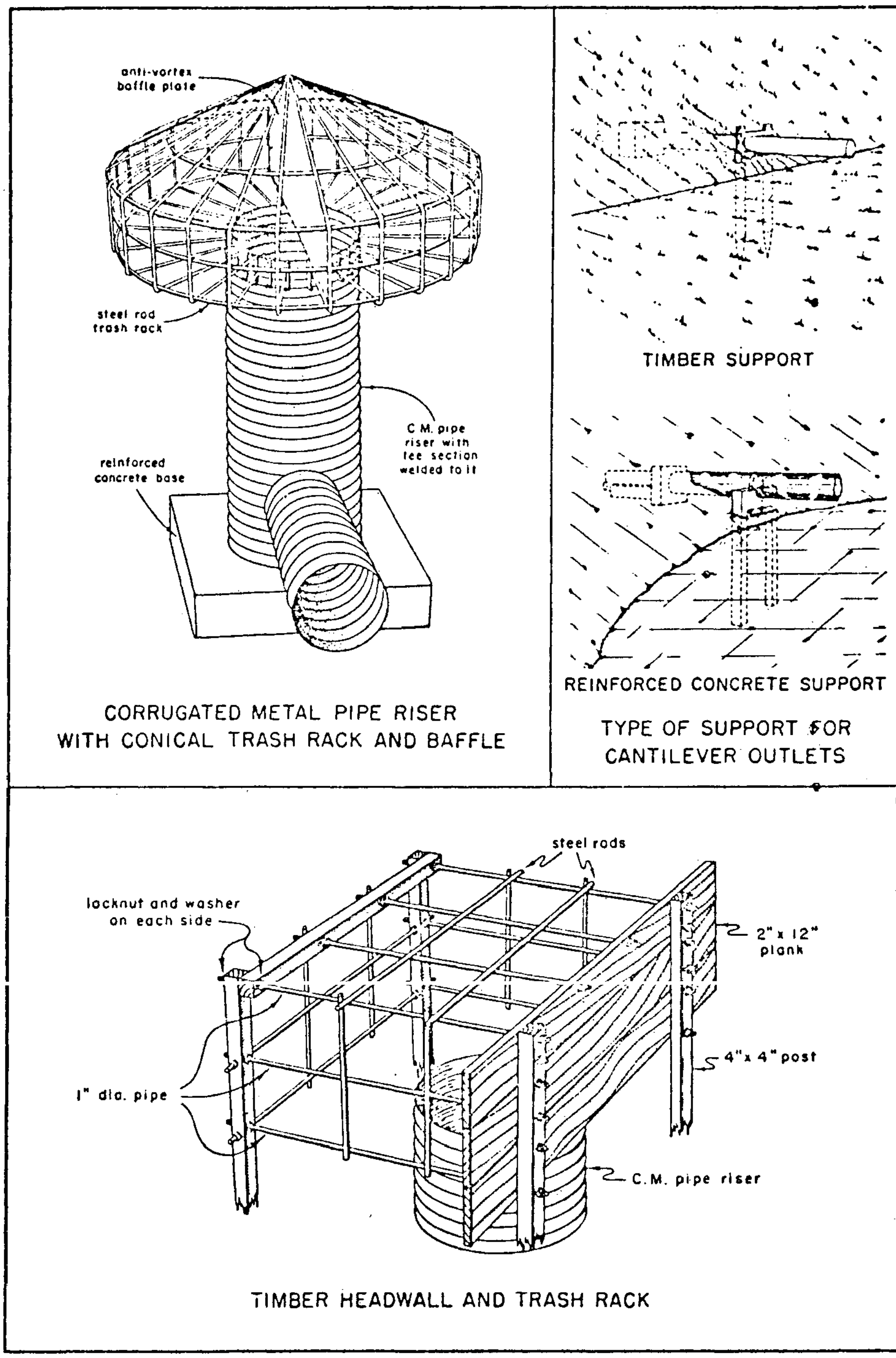
Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Engineering Practices, (1969). p. 6-37.

practically all pipe installations. The only exceptions are for watersheds with virtually no timber and none near the structure. Then a very careful evaluation is needed, since garbage or other trash may be a problem. Drop inlets always need such a rack to exclude cattle and people, the young of both groups being the most susceptible to falling into the inlet.

Figures 4-21 and 4-22 illustrate several types of trash racks. A reasonable rule of thumb is to provide at least 6 times as much inlet surface on the trash rack as is provided in the spillway inlet structure.

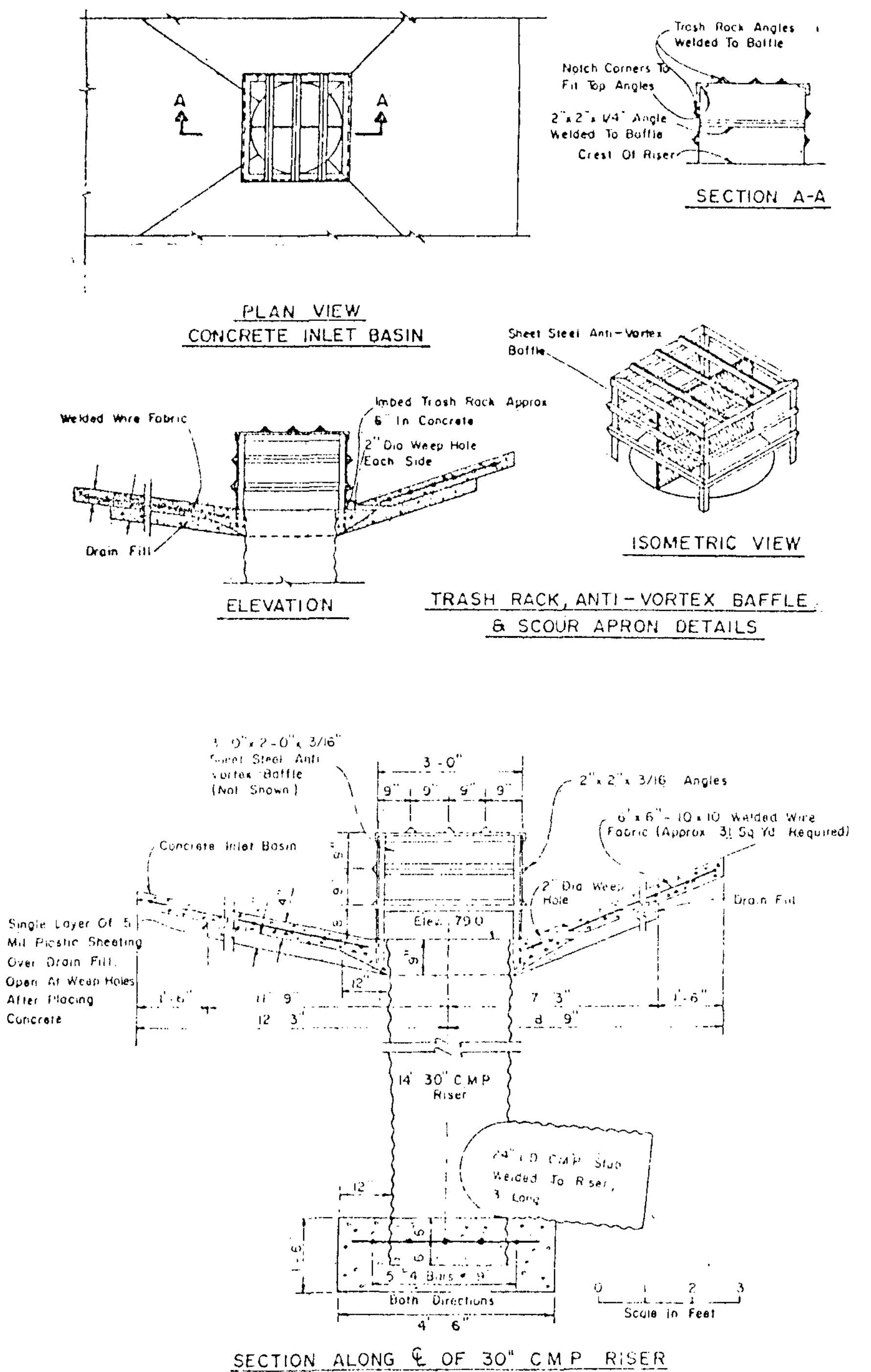
A splitter is needed on drop inlets and is normally included

Figure 4-21. Appurtenance for Metal Pipe Drop Inlets.



Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 6-35.

Figure 4-22. Details of A Trash Rack For A 30 Inch Riser.



in the trash rack design. This helps prevent vortex development. A baffle on a hood inlet serves the same function.

Pipe Type and Coating

There is no particular reason for preference between helical and annular pipe. The connection requirement will serve to exclude most helical pipe, which may be for the better. There is some uncertainty as to the life prospect of the helical pipe which is welded, since this weld is not protected by zinc.

The pipe in gully structures is exposed to an ideal corrosion environment, mainly due to oxidation. There may also be a galvanic hazard. Being a good insulator and sealant, a bituminous coating is usually specified. The petroleum pinch will undoubtedly lead to use of substitutes such as pitch resin. To be effective, the coating, especially on the outside of the pipe, must be in perfect repair when the pipe is buried.

When pipe diameter is less than 24 inches, 14-gauge metal should be sufficient for fills up to 20 feet. When diameter is in the 30 to 42 inch category at least 12-gauge metal is needed. Larger sizes require special design consideration beyond the scope of this discussion.

Foundation Drainage

Many structure sites will have seepage that must be collected, and most reinforced concrete structures present flotation or uplift problems that require relief drainage. Drain material meeting ASTM Designation C33 requirements for concrete sand or Number 8 gravel can be used in most cases for drain fill. Such materials are compatible with slots or perforations in the collector system of 1/8-inch or smaller.

Large cross section blind drains (filter without collector) offer advantages on most gully sites. Limited working space makes it hard to keep from damaging an extensive subsurface pipe system. A short collector system is needed. This need can usually be filled with perforated polyethylene tubing. This material should not be used under more than about seven feet of fill.

Situations involving large or expensive structures, highly pervious foundations, or high downstream damage hazard require careful, detailed drain investigation and design beyond the intended scope of this discussion. Further details are available in SCS Soil Mechanics Notes 1 and 3.

Emergency By-Passes

The consequences of overtopping make it imperative to protect earth embankment dams with emergency by-pass systems. When these embankments impound little water, the main consequence of overtopping is destruction of the gully-control structure. If there is significant impoundment, the features downstream become a consideration, since they, too, might be damaged. When there is possibility of damage to fixed improvements such as roads or hazard to life, the criteria presented here are inadequate for design of the emergency by-pass. Criteria presented in SCS Engineering Memorandum 27 offers guidance for these situations (7).

It is common practice in embankment-type grade control structures to set the crest of the emergency spillway one foot above the water surface elevation required to pass the principal spillway design peak rate of discharge. This one foot allowance overcomes some of the uncertainties introduced by "cookbook design" of the principal spillway.

The 25-year, 24-hour rainfall is used to set capacity and size for smaller gullies. The 50-year, 24-hour rainfall is used if any of the following limits is satisfied:

30' Head Drop $< 40'$

24" Pipe Diameter $< 36"$

100 Principal s/w Capacity < 250 cfs

If the upper limits for the 50-year range are exceeded, the design is beyond the scope of this manual (6, 8).

Tables 4-12 and 4-13 may be used for sizing the emergency spillway. The tables include self-explanatory examples. These tables are based on the assumption that good vegetation will be maintained in the emergency spillway.

Evaluating Culvert Hydraulics

It is sometimes necessary to determine whether a road culvert will handle the required design discharge or possibly control discharge requirements for design of a gully structure because of limited capacity. Possible overtopping of the road has radical effect on design requirements for a gully structure immediately downstream from the road.

If a gully has worked its way to a road and is undermining the culvert, it is pretty safe to assume the culvert is currently operating under inlet control. Flow is controlled essentially by culvert size and entrance geometry. Figure 4-23 illustrates the water surface profile in culverts under inlet control for various types of entrance geometry. Figures 4-24 and 4-25 can be used to estimate capacity or elevation of water at the entrance for a particular discharge rate. Note that several entrance conditions are represented on each chart.

HW = vertical distance from entrance invert to the entrance water surface

D = culvert diameter or height

Table 4-12. Design Table For Vegetated Spillways Excavated In Very Erodible Soils.

Side Slopes - 3 Horiz. to 1 Vert.

Discharge Q CFS	Slope Range Minimum Percent	Slope Range Maximum Percent	Bottom Width Feet	Stage Feet
10	3.5	4.7	8	.68
15	3.4	4.4	12	.69
	3.4	5.9	16	.60
20	3.3	3.3	12	.80
	3.3	4.1	16	.70
	3.5	5.3	20	.62
25	3.3	3.3	16	.79
	3.3	4.0	20	.70
	3.5	4.9	24	.64
30	3.3	3.3	20	.78
	3.3	4.0	24	.71
	3.4	4.7	28	.65
	3.4	5.5	32	.61
35	3.2	3.2	24	.77
	3.3	3.9	28	.71
	3.5	4.6	32	.66
	3.5	5.2	36	.62
40	3.3	3.3	28	.76
	3.4	3.8	32	.71
	3.4	4.4	36	.67
	3.4	5.0	40	.64
45	3.3	3.3	32	.76
	3.4	3.8	36	.71
	3.4	4.3	40	.67
	3.4	4.8	44	.64
50	3.3	3.3	36	.75
	3.3	3.8	40	.71
	3.3	4.3	44	.68
60	3.2	3.2	44	.75
	3.2	3.7	48	.72
70	3.3	3.3	52	.75
80	3.1	3.1	56	.78

Example of Use

Given: Discharge, Q=38 c.f.s. Spillway slope, exit section (from profile) =4%.

Find: Bottom Width and Stage in Reservoir.

Procedure: Enter table from left at 40 c.f.s. Note that spillway slope (4.0%) falls within slope ranges corresponding to bottom widths of 36 and 40 feet. Use narrower bottom width, 36 feet, to minimize meandering. Stage in Reservoir will be 0.67 feet.

Note: Computations based on: Roughness coefficient, n=.040
Maximum velocity=3.50 ft. per sec.

Source: U.S. Department of Agriculture, Soil Conservation Service, <u>Engineering Field Manual For Conservation Practices</u> (1969), p. 11-54.

Table 4-13. Design Table For Vegetated Spillways Excavated In Erosion Resistant Soils.

Side slopes - 3 Horiz. to 1 Vert.

Discharge Q CFS	Slope Range Minimum Percent	Slope Range Maximum Percent	Bottom Width Feet	Stage Feet
15	3.3	12.2	8	.83
	3.5	18.2	12	.69
20	3.1	8.9	8	.97
	3.2	13.0	12	.81
	3.3	17.3	16	.70
25	2.9	7.1	8	1.09
	3.2	9.9	12	.91
	3.3	13.2	16	.79
	3.3	17.2	20	.70
30	2.9	6.0	8	1.20
	3.0	8.2	12	1.01
	3.0	10.7	16	.88
	3.3	13.8	20	.78
35	2.8	5.1	8	1.30
	2.9	6.9	12	1.10
	3.1	9.0	16	.94
	3.1	11.3	20	.85
	3.2	14.1	24	.77
40	2.7	4.5	8	1.40
	2.9	6.0	12	1.18
	2.9	7.6	16	1.03
	3.1	9.7	20	.91
	3.1	11.9	24	.83
45	2.6	4.1	8	1.49
	2.8	5.3	12	1.25
	2.9	6.7	16	1.09
	3.0	8.4	20	.98
	3.0	10.4	24	.89
50	2.7	3.7	8	1.57
	2.8	4.7	12	1.33
	2.8	6.0	16	1.16
	2.9	7.3	20	1.03
	3.1	9.0	24	.94
60	2.6	3.1	8	1.73
	2.7	3.9	12	1.47
	2.7	4.8	16	1.28
	2.9	5.9	20	1.15
	2.9	7.3	24	1.05
	3.0	8.6	28	.97
70	2.5	2.8	8	1.88
	2.6	3.3	12	1.60
	2.6	4.1	16	1.40
	2.7	5.0	20	1.26
	2.8	6.1	24	1.15
	2.9	7.0	28	1.05
80	2.5	2.9	12	1.72
	2.6	3.6	16	1.51
	2.7	4.3	20	1.35

Discharge Q CFS	Slope Range Minimum Percent	Slope Range Maximum Percent	Bottom Width Feet	Stage Feet
80	2.8	5.2	24	1.24
	2.8	5.9	28	1.14
	2.9	7.0	32	1.08
90	2.5	2.6	12	1.84
	2.5	3.1	16	1.61
	2.6	3.8	20	1.45
	2.7	4.5	24	1.32
	2.8	5.3	28	1.22
	2.8	6.1	32	1.14
100	2.5	2.8	16	1.71
	2.6	3.3	20	1.54
	2.6	4.0	24	1.41
	2.7	4.8	28	1.30
	2.7	5.3	32	1.21
	2.8	6.1	36	1.13
120	2.5	2.8	20	1.71
	2.6	3.2	24	1.56
	2.7	3.8	28	1.44
	2.7	4.2	32	1.34
	2.7	4.8	36	1.26
140	2.5	2.7	24	1.71
	2.5	3.2	28	1.58
	2.6	3.6	32	1.47
	2.6	4.0	36	1.38
	2.7	4.5	40	1.30
160	2.5	2.7	28	1.70
	2.5	3.1	32	1.58
	2.6	3.4	36	1.49
	2.6	3.8	40	1.40
	2.7	4.3	44	1.33
180	2.4	2.7	32	1.72
	2.4	3.0	36	1.60
	2.5	3.4	40	1.51
	2.6	3.7	44	1.43
200	2.5	2.7	36	1.70
	2.5	2.9	40	1.60
	2.5	3.3	44	1.52
	2.6	3.6	48	1.45
220	2.4	2.6	40	1.70
	2.5	2.9	44	1.61
	2.5	3.2	48	1.53
240	2.5	2.6	44	1.70
	2.5	2.9	48	1.62
	2.6	3.2	52	1.54
260	2.4	2.6	48	1.70
	2.5	2.9	52	1.62
280	2.4	2.6	52	1.70
300	2.5	2.6	56	1.69

Example of Use

Given: Discharge, Q=87 c.f.s. Spillway Slope, Exit section (from profile)= 4%.

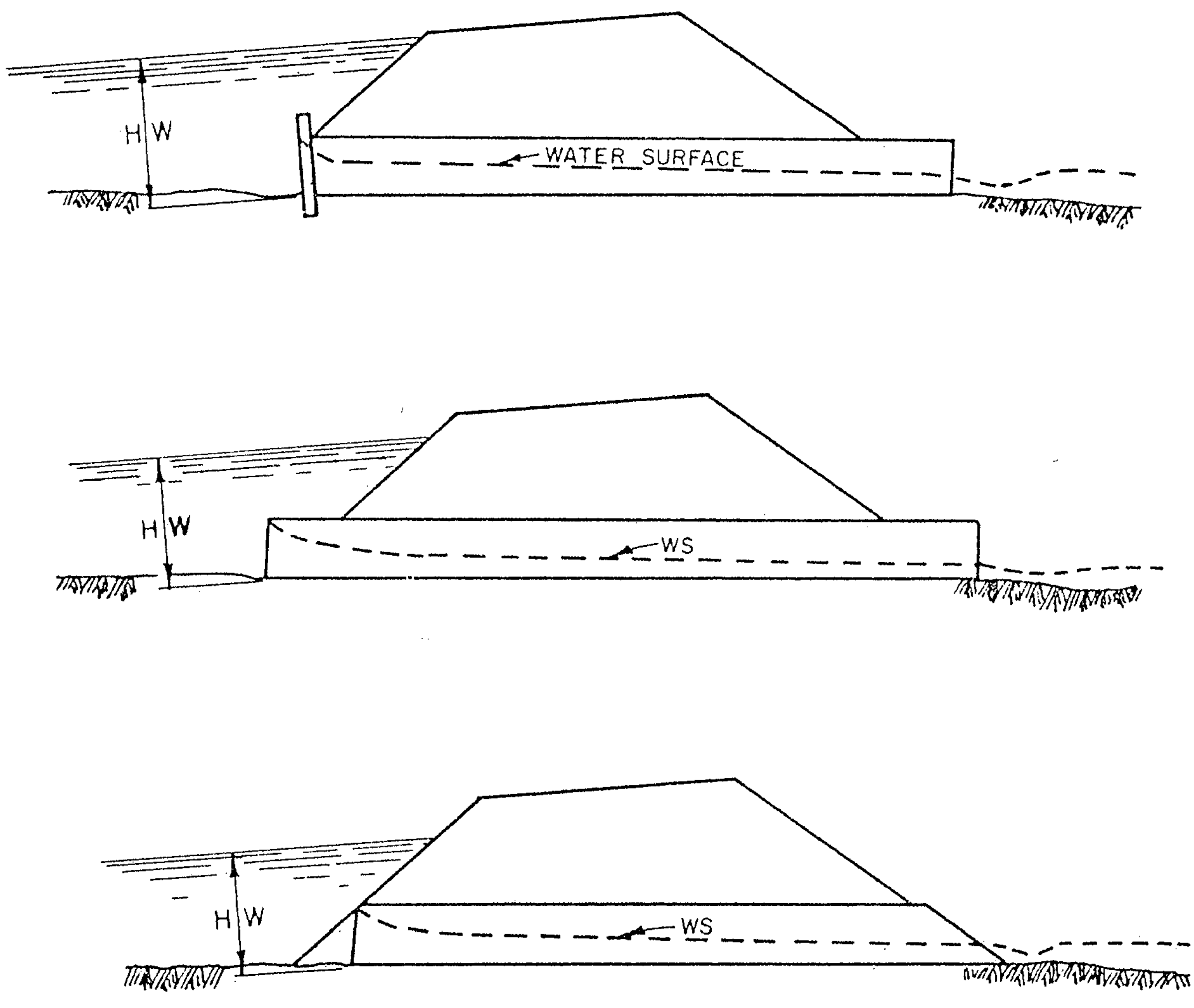
Find: Bottom Width and Stage in Reservoir.

Procedure: Enter table from left at 90 c.f.s. Note that spillway slope (4%) falls within slope ranges corresponding to bottom widths of 24, 28, and 32 feet. Use narrower bottom width, 24 feet, to minimize meandering. Stage in Reservoir will be 1.32 feet.

Note: Computations based on: Roughness coefficient, n=.040. Maximum velocity=5.50 ft. per sec.

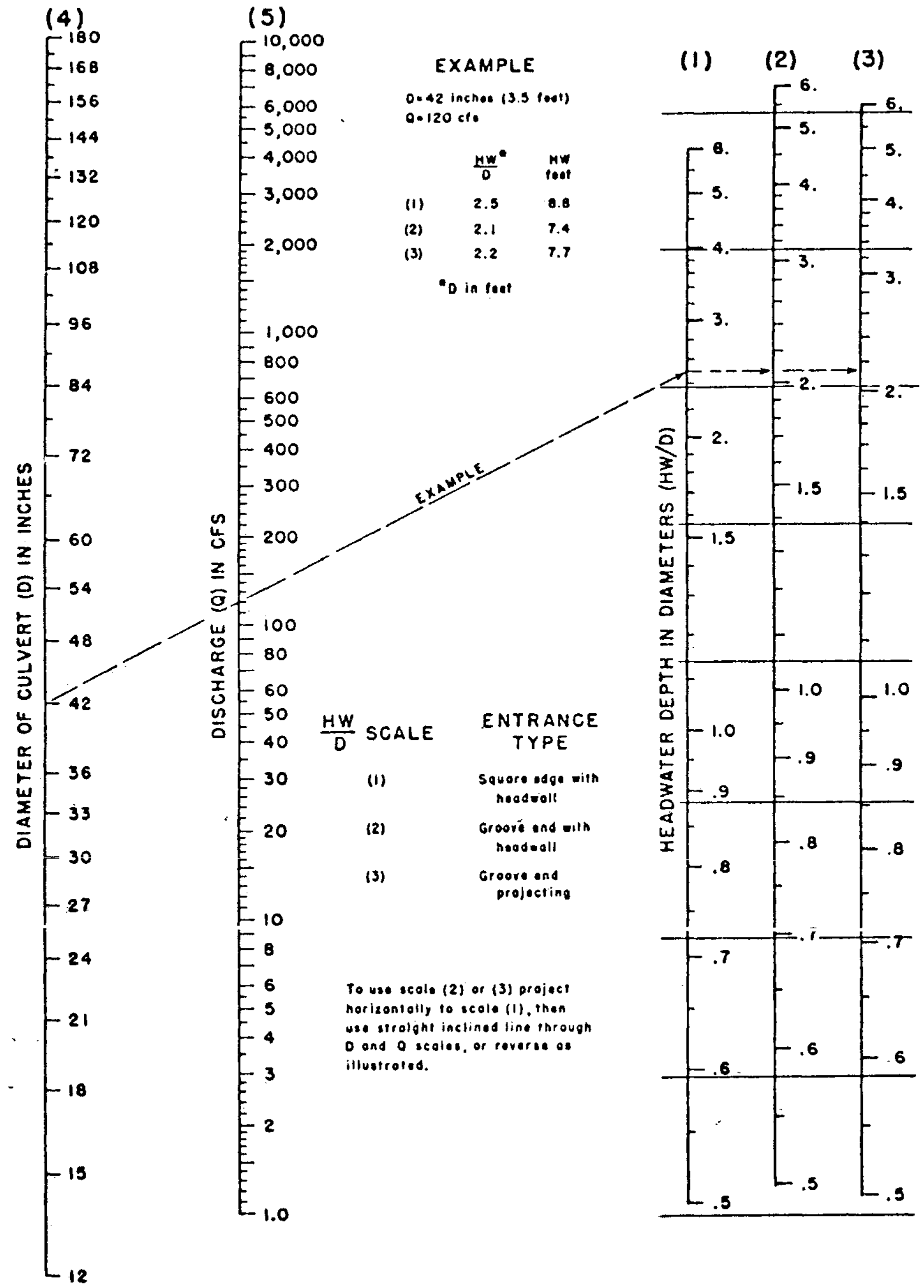
Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 11-53.

Figure 4-23. Culverts With Inlet Control.



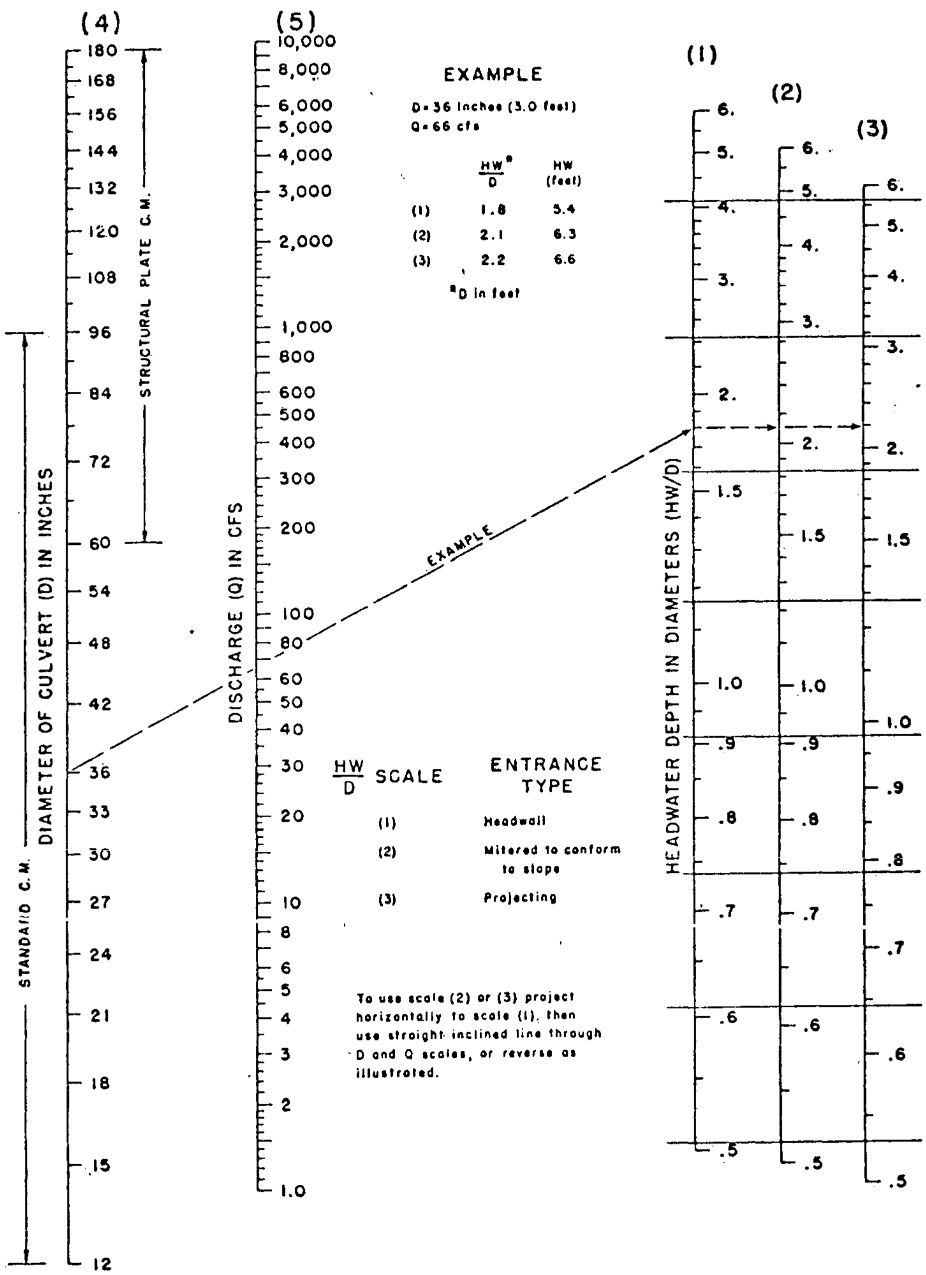
Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 3-31.

Figure 4-24. Headwater Depth For Concrete Pipe Culverts With Inlet Control.



Source: U.S. Department of Commerce, Bureau of Public Roads, Hydraulic Charts for the Selection of Highway Culverts, Hydraulic Engineering Circular Number 5, (April, 1964), p. 5-22.

Figure 4-25. Headwater Depth For CM Pipe Culverts With Inlet Control.



Source: U.S. Department of Commerce, Bureau of Public Roads, Hydraulic Charts for the Selection of Highway Culverts, Hydraulic Engineering Circular Number 5, (April, 1964), p. 5-25.

When a structure downstream may cause tailwater, or some other condition may cause tailwater, either inlet or outlet conditions may control flow. Both possibilities must be assessed. The condition dictating the deepest water at the inlet for the design or trial discharge is the controlling condition. Conversely, the lowest discharge for a given head, HW, also would indicate the control. Figure 4-26 illustrates several possible configurations of outlet control and general water depth relationships.

Figures 4-27 and 4-28 give discharge under outlet control conditions as a function of HW. To use these charts it is first necessary to evaluate tailwater, TW, in feet above the outlet invert. This will sometimes be the design elevation for the water surface at a gully structure immediately downstream. If TW is equal to or greater than the top of the culvert at its outlet, set $TW = h_o$ and solve for HW in formula 4-1 (9).

$$HW = H + h_o - L S_o \qquad (4\text{-}1)$$

HW = vertical distance from culvert invert to water surface at inlet in feet

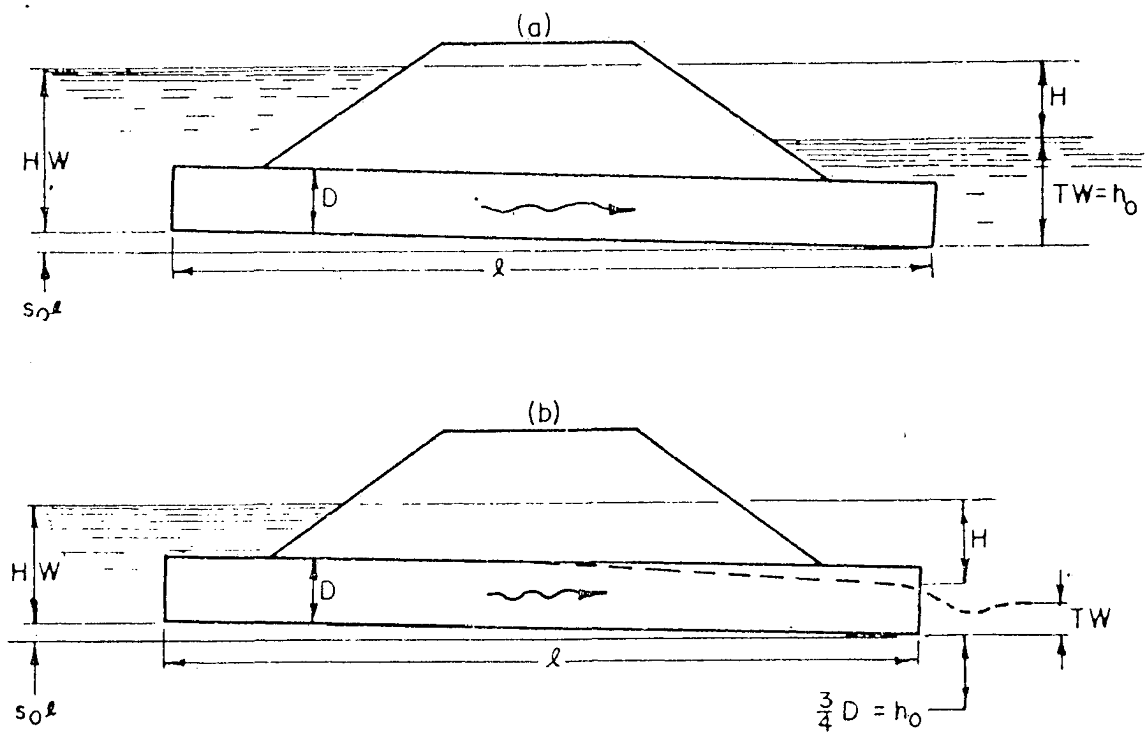
A = head loss determined from figures in feet

h_o = vertical distance from culvert invert at outlet to hydraulic grade line in feet

S_o = slope of barrel in ft/ft

L = length of culvert in feet

Figure 4-26. Culvert Water Depth Relationships.



Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practice (1969), p. 3-36.

If tailwater is below the top of the culvert, h_o is taken for simplicity as 3/4 D (1, p. 3.35-3.36). When HW has been determined, select an appropriate entrance loss coefficient from Table 4-14 and enter Figure 4-27 or 4-28.

Flumes

Lined flumes (lined waterways) are not often used as a gully renovation measure on major gullies except in deteriorated roadside

Table 4-14. Entrance Loss Coefficients.

Type of Structure and Design of Entrance	Coefficient K_e
Pipe, Concrete	
Projecting from fill, socket end (groove end)	0.2
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove end)	0.2
Square-end	0.5
Rounded (radius = 1/12D)	0.2
Mitered to conform to fill slope	0.7
*End-section conforming to fill slope	0.5
Pipe, or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls	
Square-edge	0.5
Mitered to conform to fill slope	0.7
*End-section conforming to fill slope	0.5

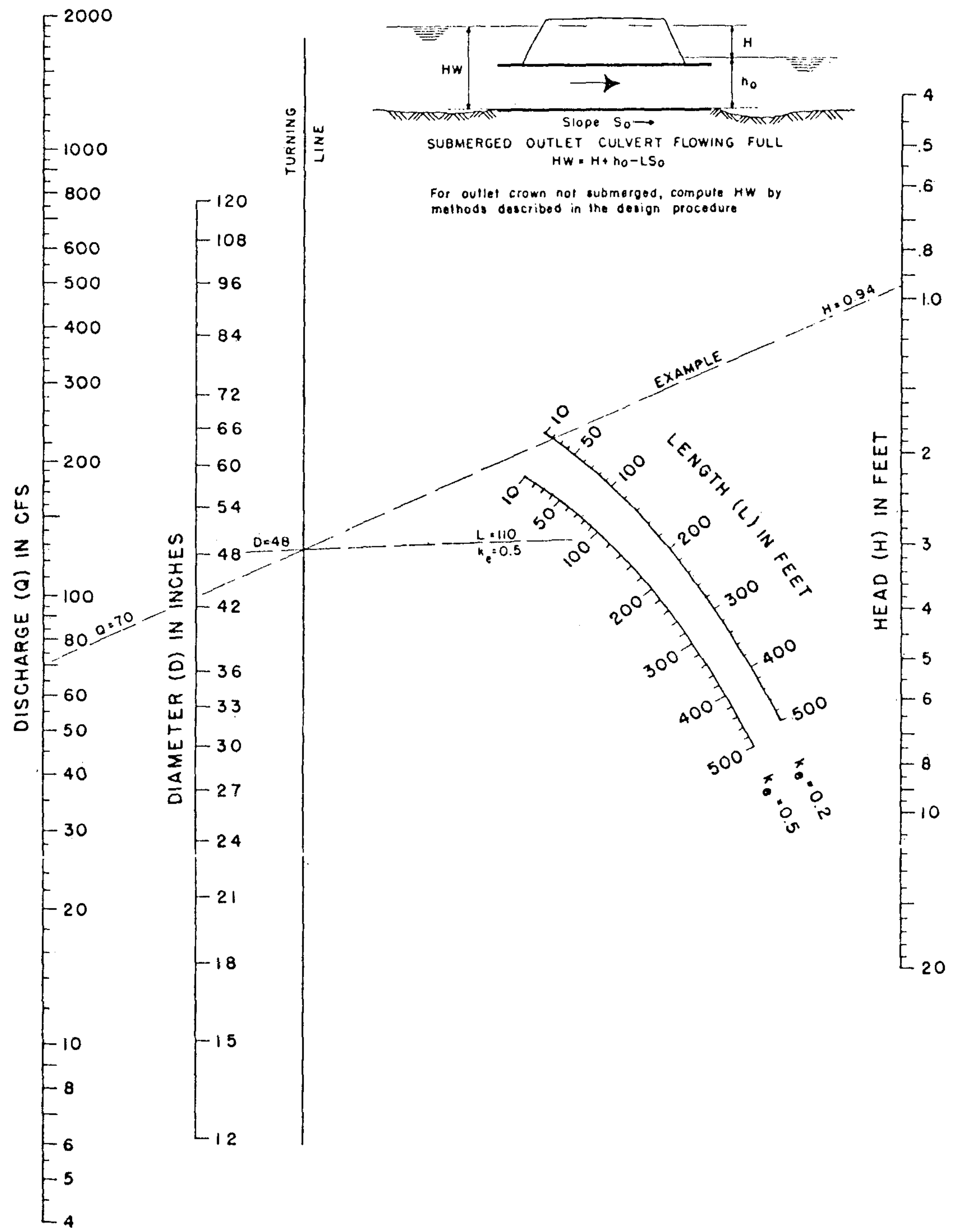
*"End-section conforming to fill slope," made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control.

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices, (1969), p. 5-49.

ditches. This need not be true. They provide efficient means of water disposal when carefully installed.

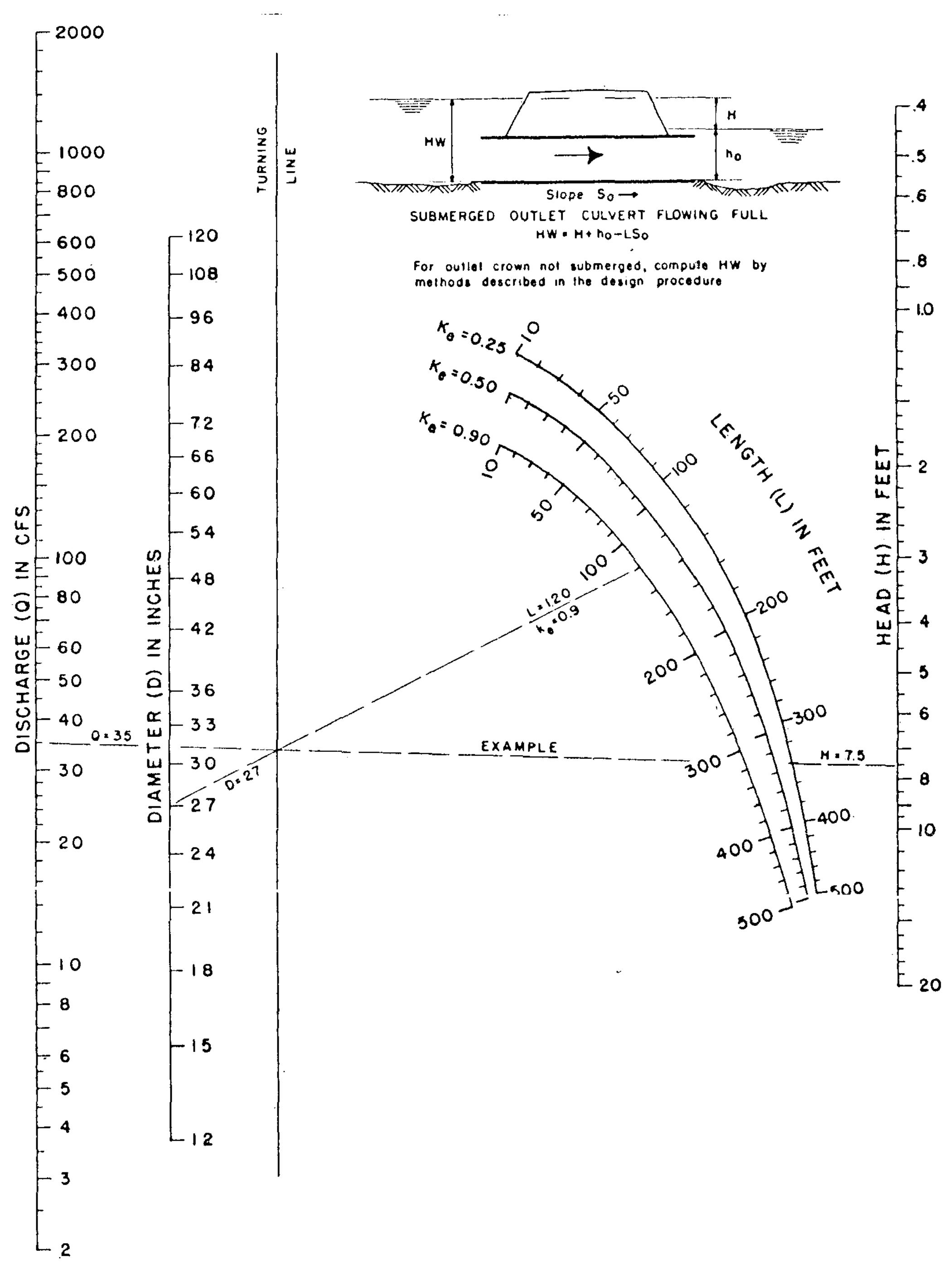
Capacities for flumes are determined using Manning's formula expressed in terms of discharge rate.

Figure 4-27. Head For Concrete Pipe Culverts Flowing Full With Outlet Control n = 0.012.



Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 3-93.

Figure 4-28. Head For CM Pipe Culverts Flowing Full With Outlet Control n = 0.024.



Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Field Manual for Conservation Practices (1969), p. 3-94.

$$Q = \frac{1.486}{n} \cdot a\, r^{2/3}\, s^{½} \qquad (4\text{-}2)$$

where $Q = av$ = rate of discharge, cubic feet per second

a = area of flow in the vertical plane, sq. ft.

v = mean flow velocity, feet per second

r = hydraulic radius

s = slope of the energy gradient, usually assumed equal to s_o for flume design, ft/ft

n = coefficient of roughness

The following Manning's roughness (n) values are representative design values (10, 11):

Concrete	
trowel finish	0.013
wood float finish	0.015
gunite	0.019
Mortared Flagstone	0.022
Riprap	$*0.04(d_{50})^{1/6}$

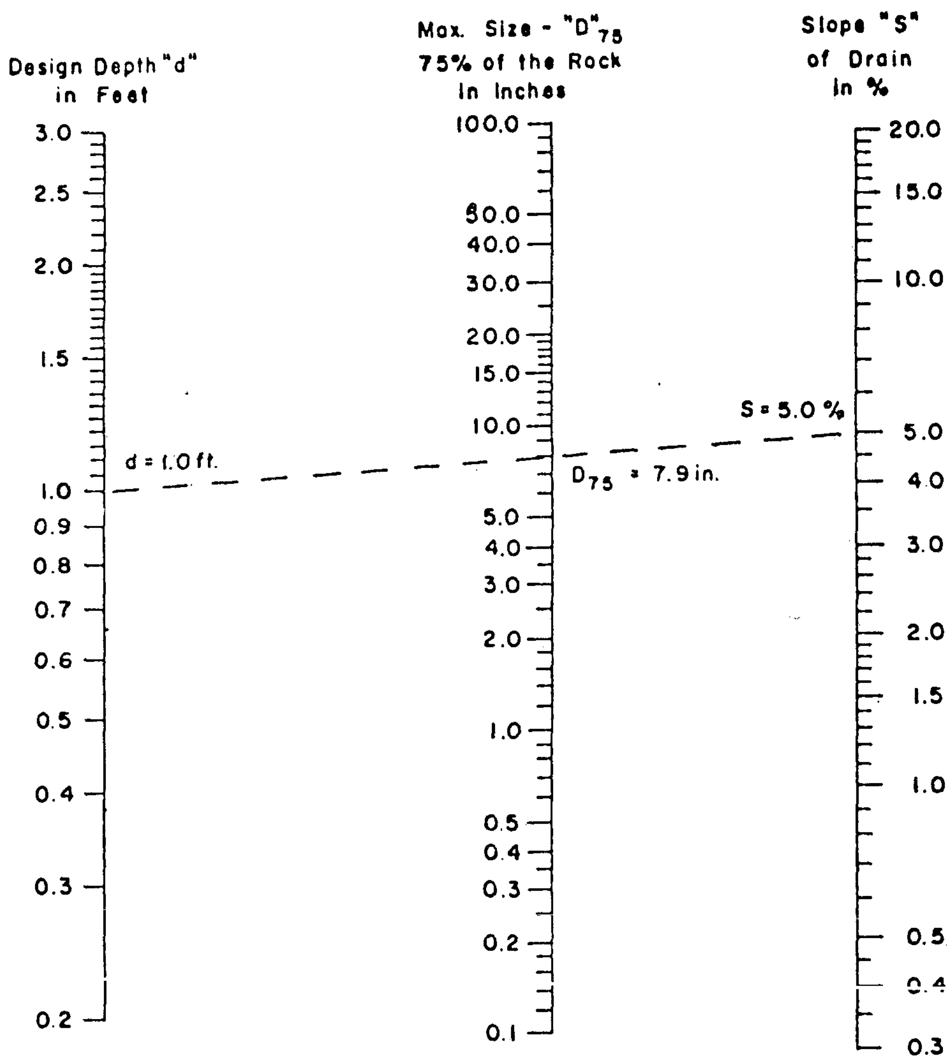
$*d_{50}$ is the mean diameter of the riprap; must be in feet.

When riprap is used, an appropriate diameter can be determined from Figure 4-29.

Administrative Restrictions

The Soil Conservation Service places important limitations on

Figure 4-29. Determination of Rock Size for Riprap Waterway.



EXAMPLE: "d" = 1.0 Feet "S" = 5%

Place straight edge at "d" value in Design Depth column and at "S" value in Slope column. Read rock size in middle column 7.9 inches. Say 8 inches.

FOR DESIGN:

25% of the rock by volume should be in sizes of 8 inches or slightly larger. The remaining 75% or less should be of well graded material, smaller than 8 inches, including sufficient sands and gravels to fill the voids between the larger rock.

Source: U.S. Department of Agriculture, Soil Conservation Service, Engineering Standard-464 from National Cooperative Highway Research Program, Report 108, Tentative Design Procedure for Riprap-Lined Channels.

the design and application of these structures. These limitations are subject to revision from time to time on the basis of experience or research information. Important current limitations are listed below (10):

1) Maximum capacity at design depth must not exceed 100 c.f.s.

2) Design capacity must be at least equal to the estimated 10-year, 24-hour peak discharge rate.

3) Except in short transitions, the critical slope (gradient) must be avoided. To prevent the associated unstable flow conditions, the gradient range of $0.7\ s_o < s_c < 1.3\ s_c$ is avoided, where s_c = critical gradient and s_o = outlet gradient.

4) Alignment must be straight when gradient and design velocity exceed critical.

5) Velocity is restricted as follows:

Design Flow Depth	Maximum Velocity
0 - 0.5'	25 fps
0.5 - 1.0'	15 fps
$>$ 1.0'	10 fps

6) Inclination of slide walls must be equal to or flatter than the following:

Non-reinforced concrete

Hand-placed, formed

Lining height $\leq$ 1.5 feet - vertical

Hand-placed, screeded or mortared flagstone

Lining height $\leqq$ 2.0 feet – 1 to 1
(horizontal to vertical)

Lining height $>$ 2.0 feet – 2 to 1

Slip form concrete

Height $\leqq$ 3.0 feet – 1 to 1

Rock Riprap – 2 to 1

7) Lining thickness must at least equal the following values:

Concrete and flagstone – 4 inches

Riprap – maximum stone diameter plus bedding or filter

Sizing of Concrete Flumes

The concrete-lined ditch, or concrete flume (as it is commonly called in Alabama), has been widely used for highway storm water disposal. It is applicable to many situations where vegetation cannot be grown in a watercourse and velocities are erosive. Flumes are normally installed with a one or two foot sod strip along each side to protect against undermining by surface flow or unexpected overflow.

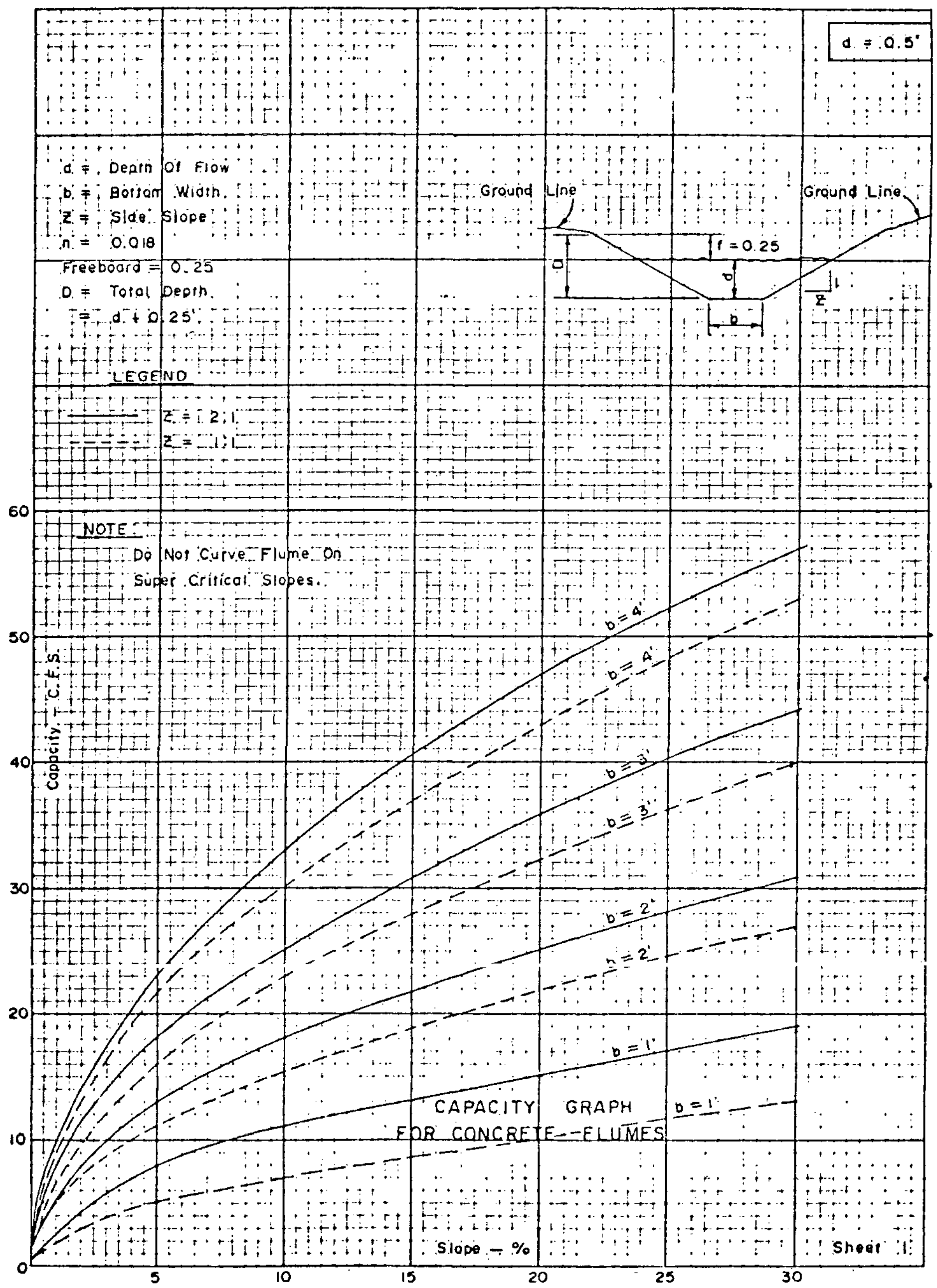
Table 4-15 and Figures 4-30 through 4-41 may be used to select a concrete flume size. A word of caution is in order, however. These figures were constructed without regard to allowable velocities, and they provide many solutions which violate design criteria stated in the previous section. These may involve

Table 4-15. Concrete Quantities For Trapezoidal Flumes.

BOTTOM WIDTH	TOTAL DEPTH	VOLUME = CU. YD. PER LINEAR FOOT			
		Z = 1 : 1	Z = 2 : 1	Z = 3 : 1	Z = 4 : 1
2' – 0"	0' – 9"	0.0508	0.0660	0.0832	0.1009
2' – 0"	1' – 0"	.0596	.0798	1027	.1264
2' – 0"	1' – 3"	.0683	.0936	.1222	.1518
2' – 0"	1' – 6"	.0770	.1074	.1417	.1772
2' – 0"	1' – 9"	.0857	.1212	1612	.2026
2' – 0"	2' – 0"	.0944	.1350	.1807	.2281
3' – 0"	0' – 9"	.0632	.0784	.0955	.1133
3' – 0"	1' – 0"	.0719	.0922	.1150	.1387
3' – 0"	1' – 3"	.0806	.1059	1345	.1641
3' – 0"	1' – 6"	.0893	.1197	.1540	.1896
3' – 0"	1' – 9"	.0980	.1335	.1735	.2150
3' – 0"	2' – 0"	.1068	.1473	.1930	.2404
4' – 0"	0' – 9"	.0755	.0907	.1078	.1256
4' – 0"	1' – 0"	.0842	.1045	.1273	.1510
4' – 0"	1' – 3"	.0929	.1183	.1468	.1765
4' – 0"	1' – 6"	.1017	.1321	.1663	.2019
4' – 0"	1' – 9"	.1104	.1459	.1858	.2273
4' – 0"	2' – 0"	.1191	.1596	.2053	.2527
1' – 0"	0' – 9"	.0385	.0537	.0708	.0886
1' – 0"	1' – 0"	.0472	.0675	.0903	.1140
1' – 0"	1' – 3"	.0559	.0813	.1098	.1395
1' – 0"	1' – 6"	.0647	.0951	.1293	.1649

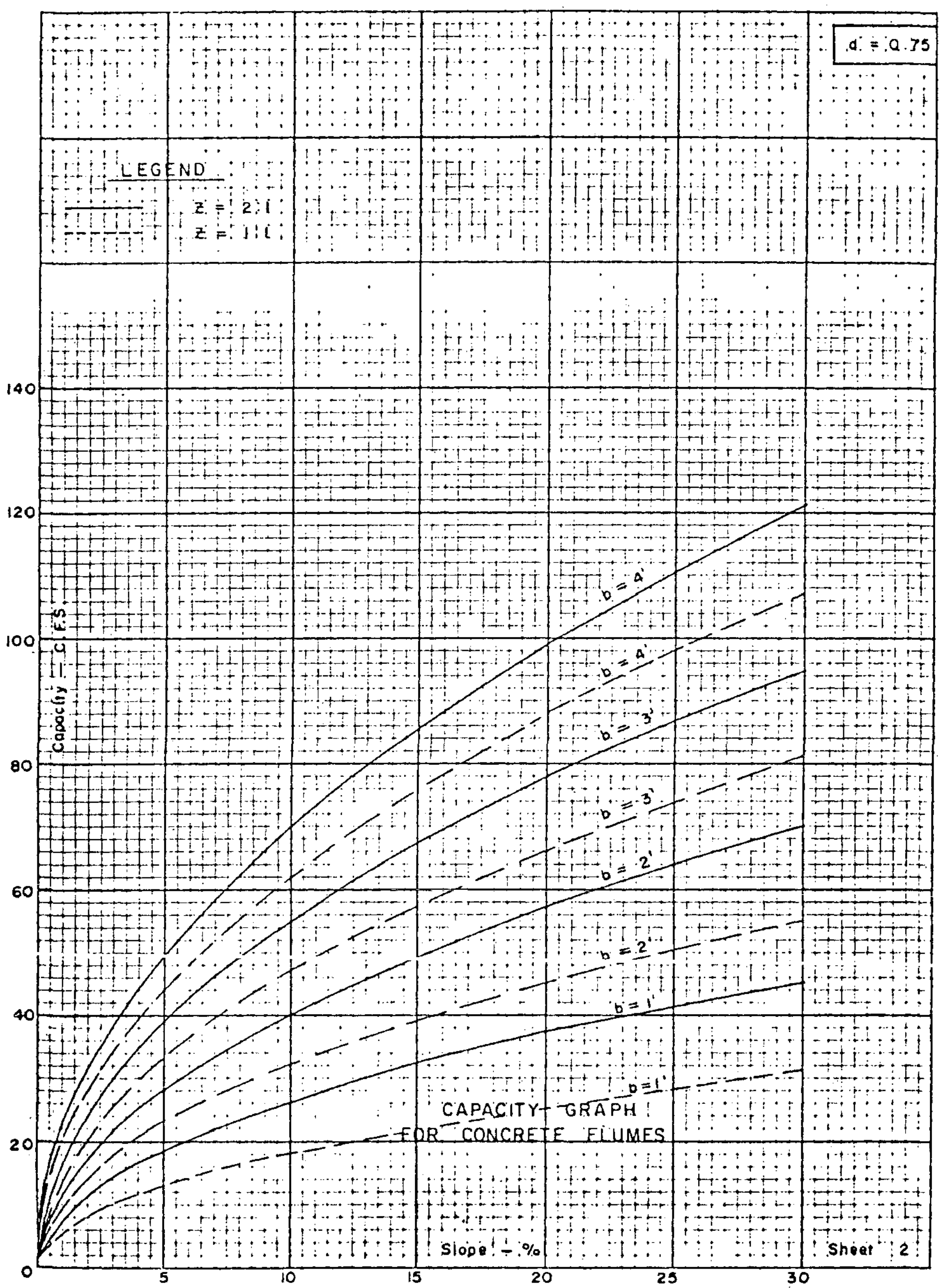
Source: U.S. Department of Agriculture, Soil Conservation Service, State Design Unit, Auburn, Alabama.

Figure 4-30. Capacity Graph For Concrete Flumes.



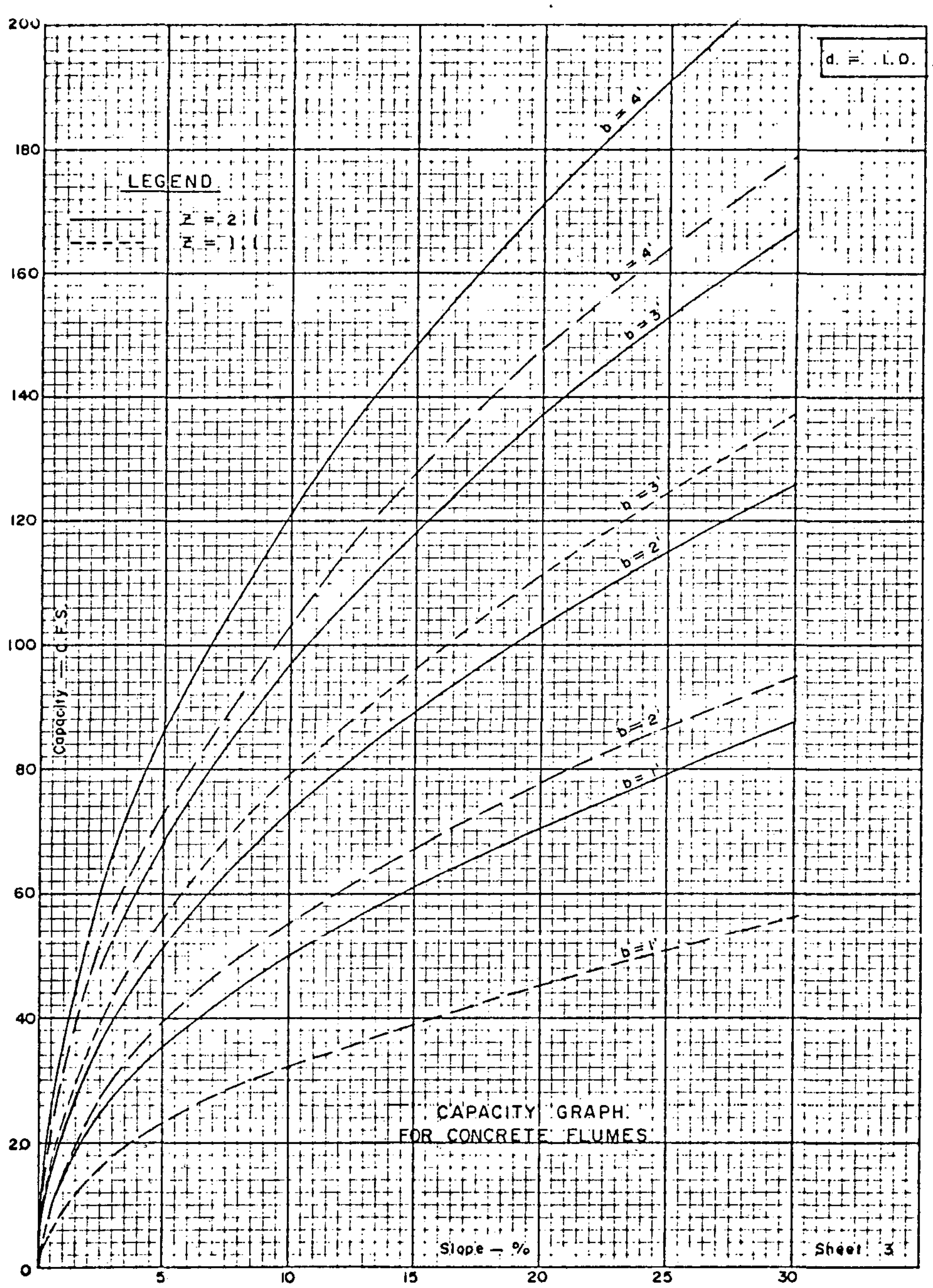
Source: U.S. Department of Agriculture, Soil Conservation Service, State Design Unit, Auburn, Alabama.

Figure 4-31. Capacity Graph For Concrete Flumes.



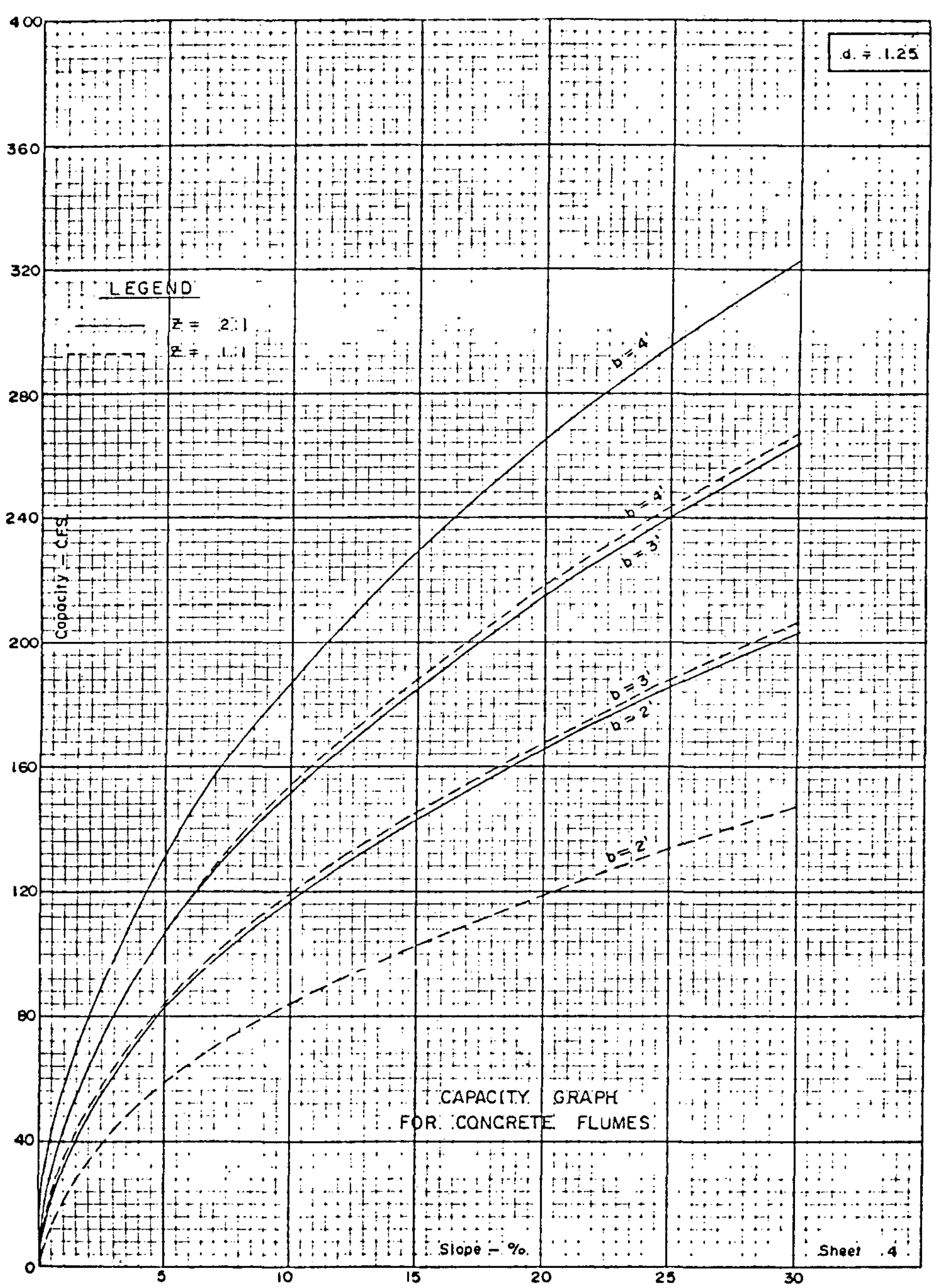
Source: U. S. Department of Agriculture, Soil Conservation Service, State Design Unit, Auburn, Alabama.

Figure 4-32. Capacity Graph For Concrete Flumes.



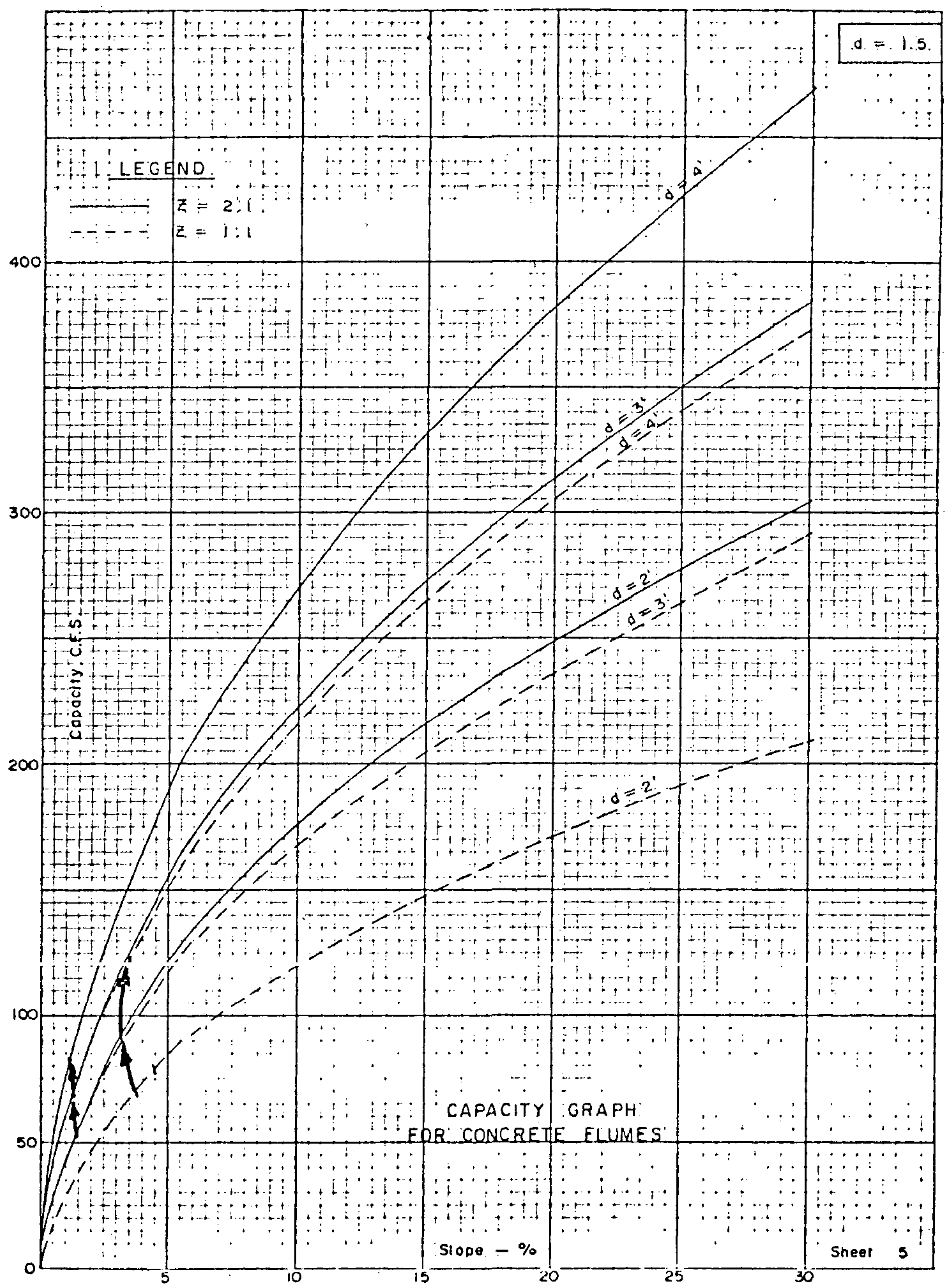
Source: U. S. Department of Agriculture, Soil Conservation Service, State Design Unit, Auburn, Alabama.

Figure 4-33. Capacity Graph For Concrete Flumes.



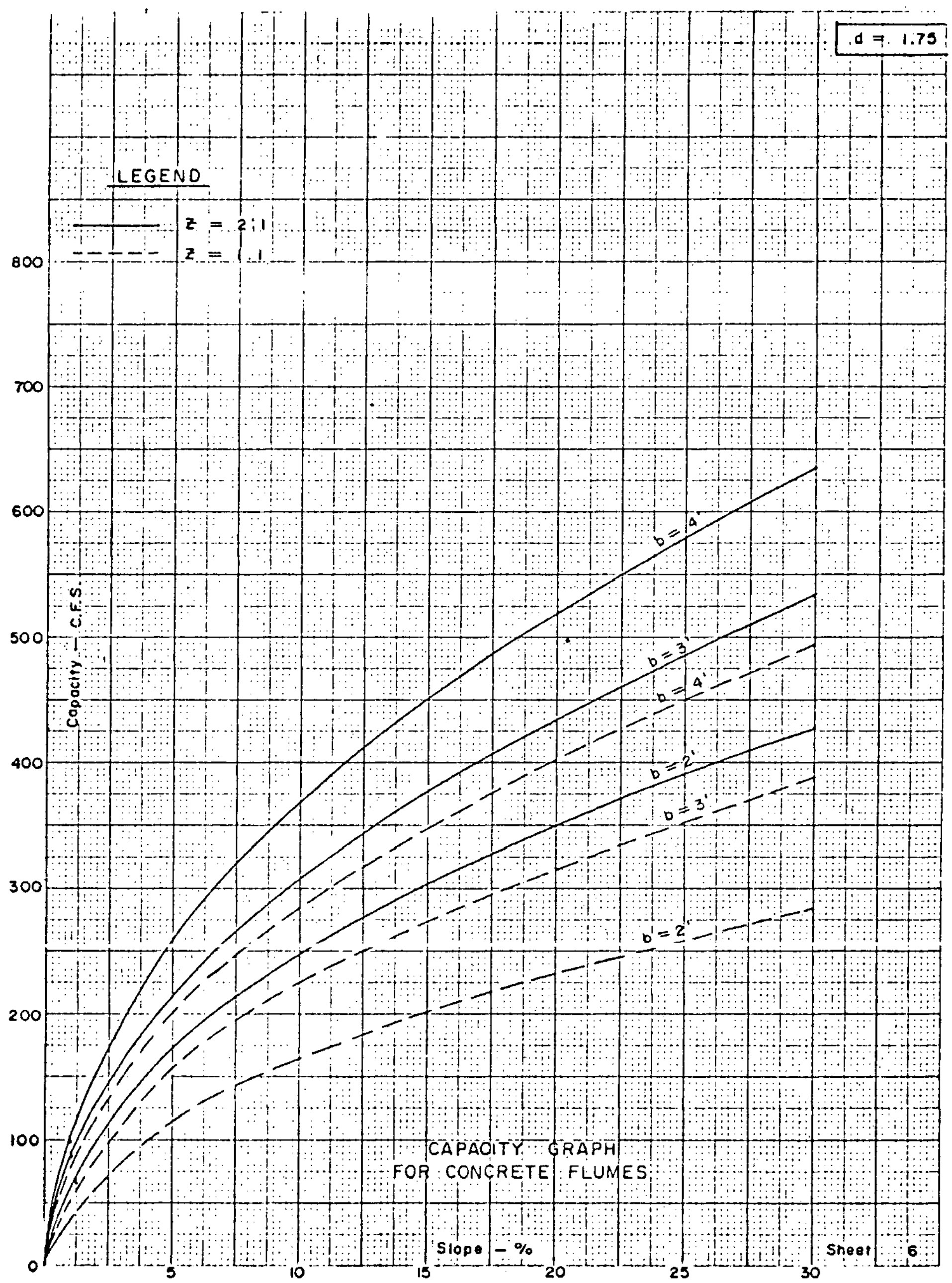
Source: U.S. Department of Agriculture, Soil Conservation Service, State Design Unit, Auburn, Alabama.

Figure 4-34. Capacity Graph For Concrete Flumes.



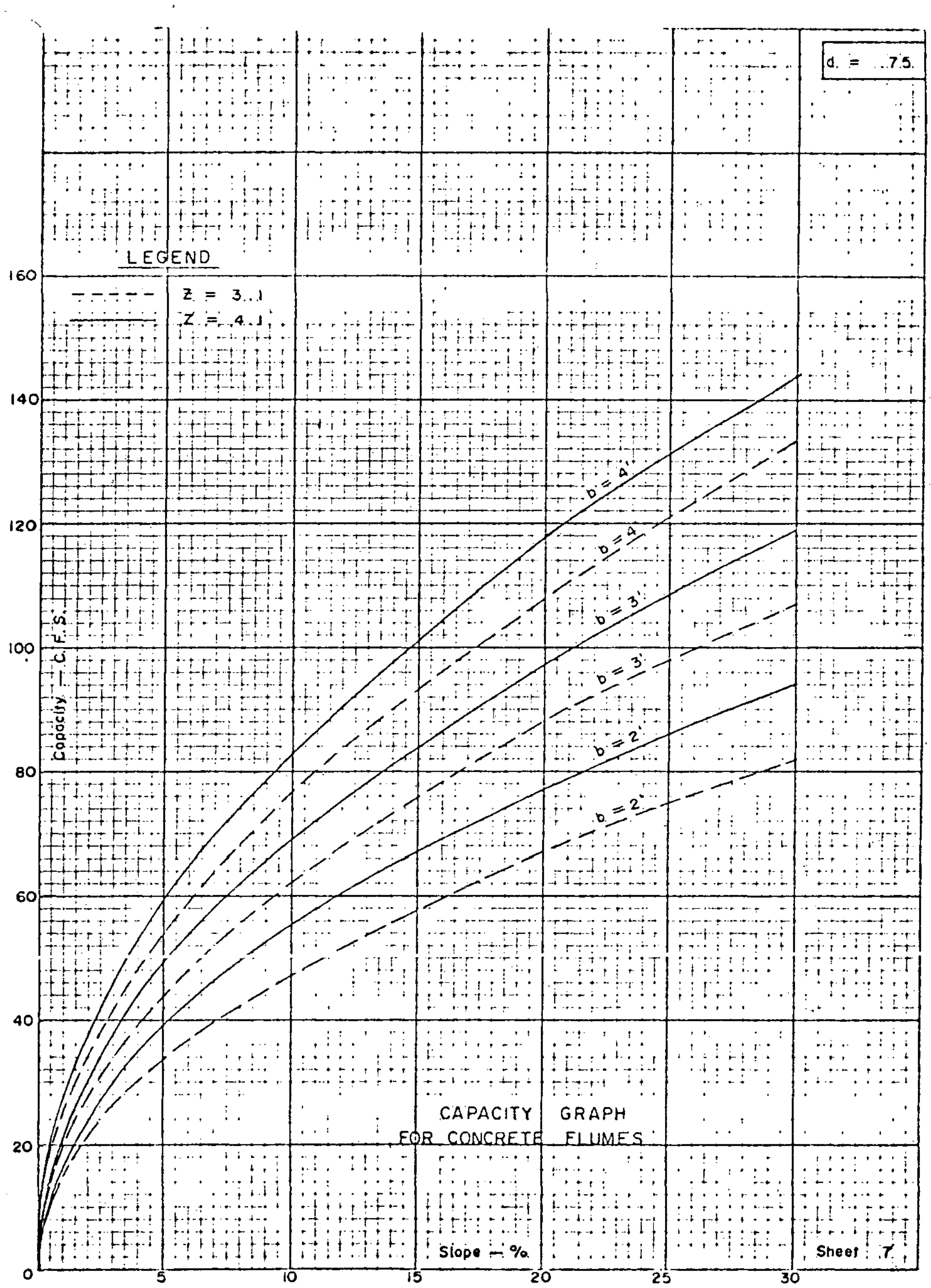
Source: U.S. Department of Agriculture, Soil Conservation Service, State Design Unit, Auburn, Alabama.

Figure 4-35. Capacity Graph for Concrete Flumes.



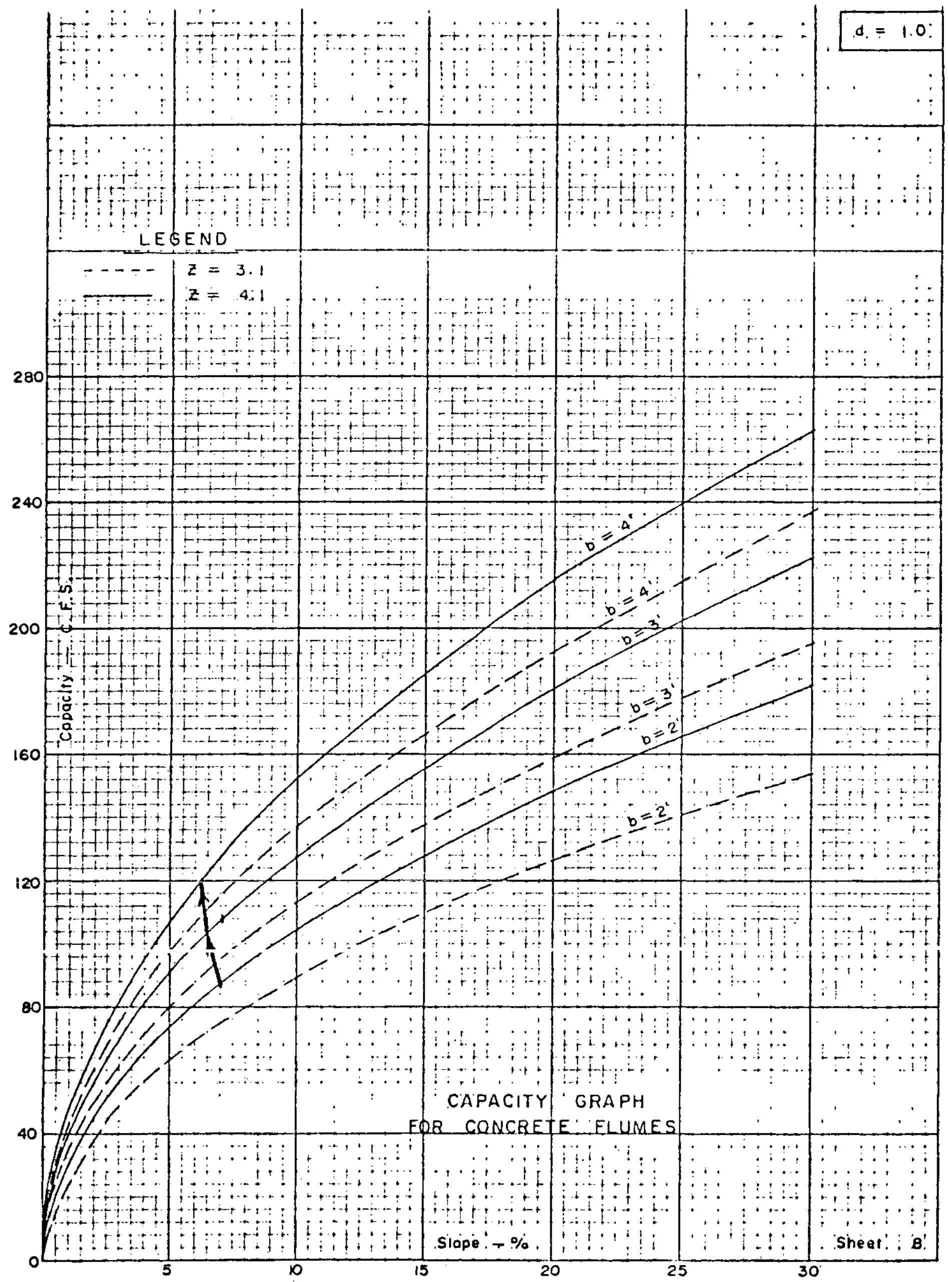
Source: U.S. Department of Agriculture, Soil Conservation Service, State Design Unit, Auburn, Alabama.

Figure 4-36. Capacity Graph For Concrete Flumes.



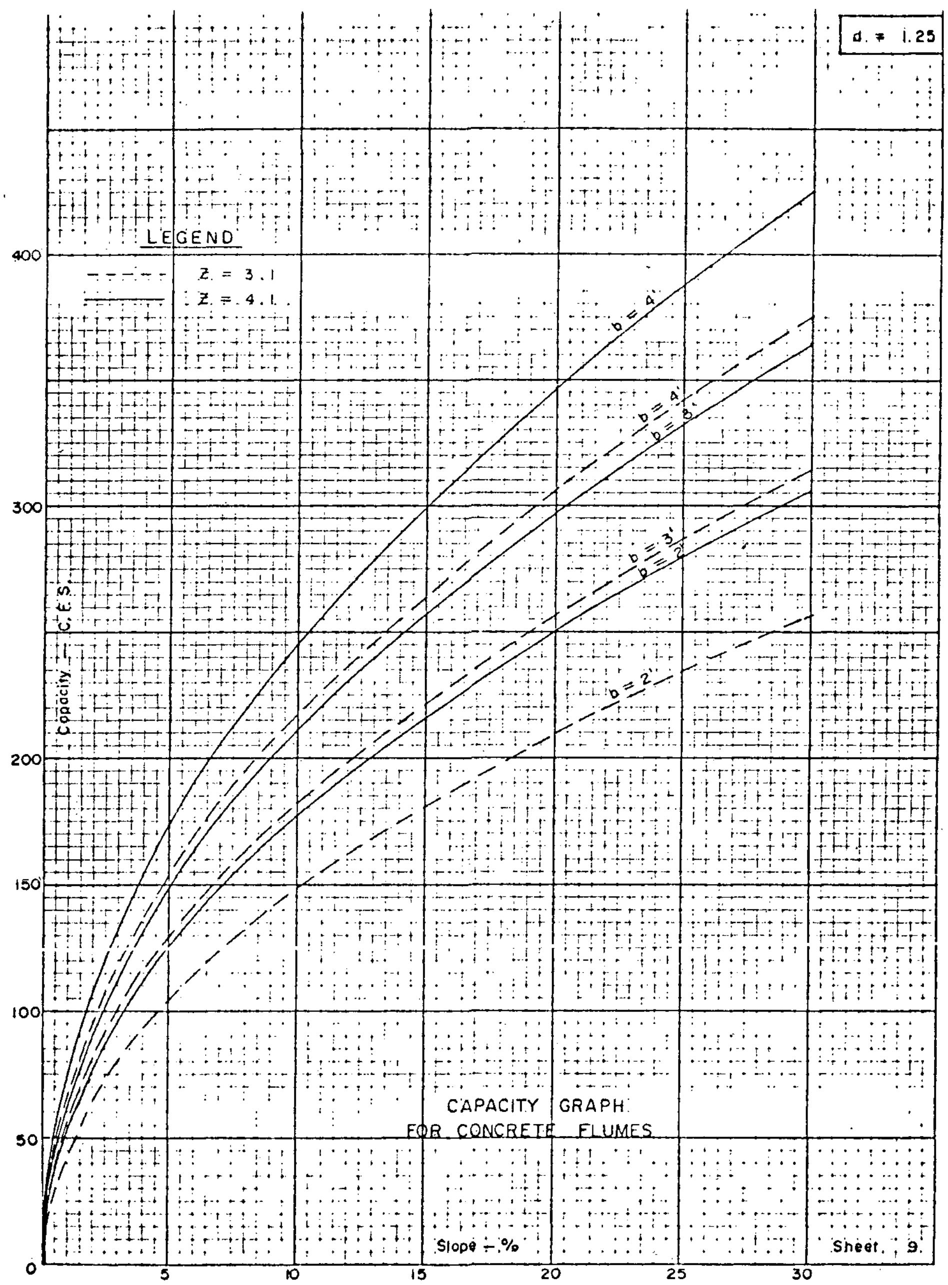
Source: U.S. Department of Agriculture, Soil Conservation Service, State Design Unit, Auburn, Alabama.

Figure 4-37. Capacity Graph For Concrete Flumes.



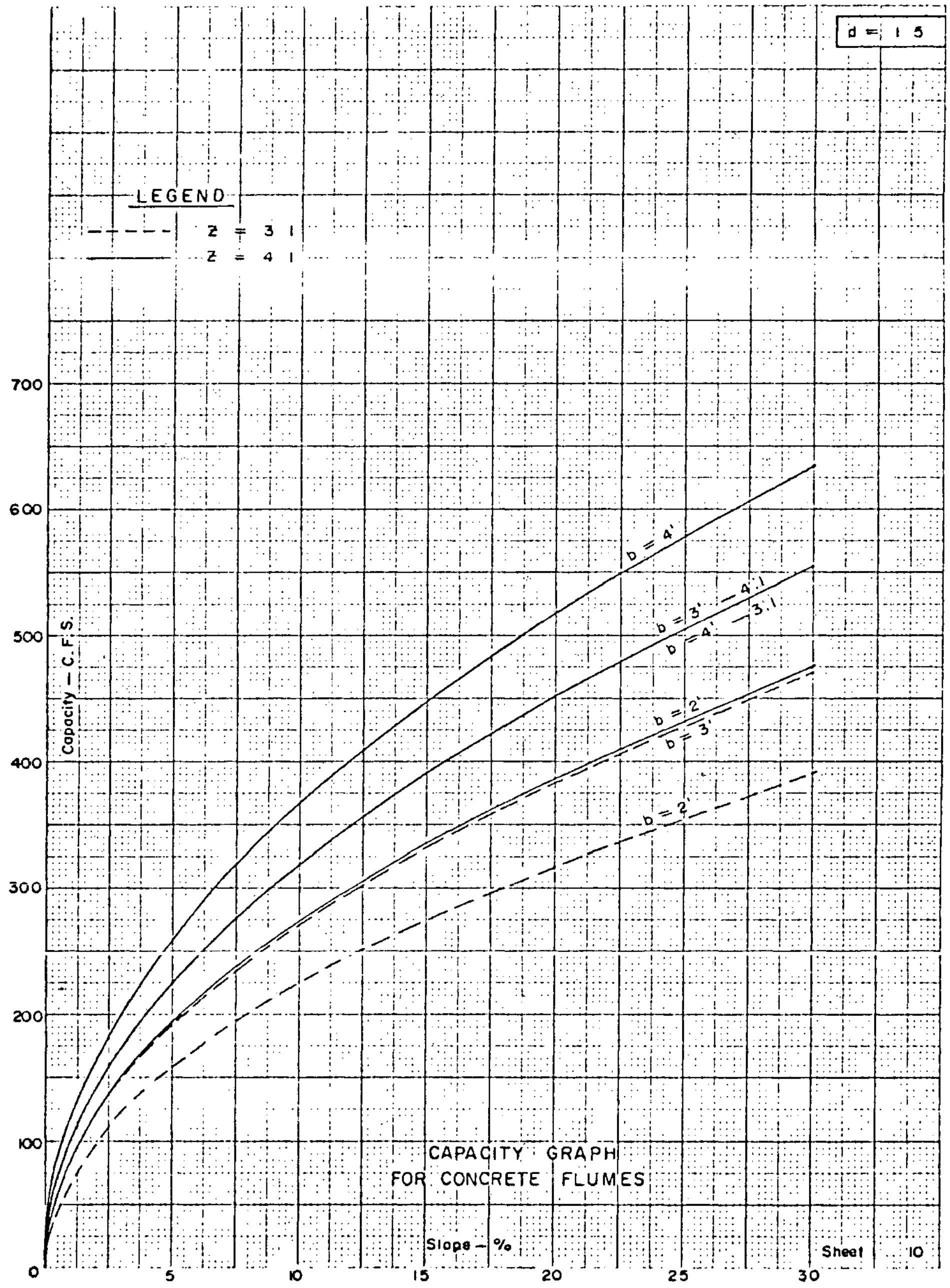
Source: U.S. Department of Agriculture, Soil Conservation Service, State Design Unit, Auburn, Alabama.

Figure 4-38. Capacity Graph For Concrete Flumes.



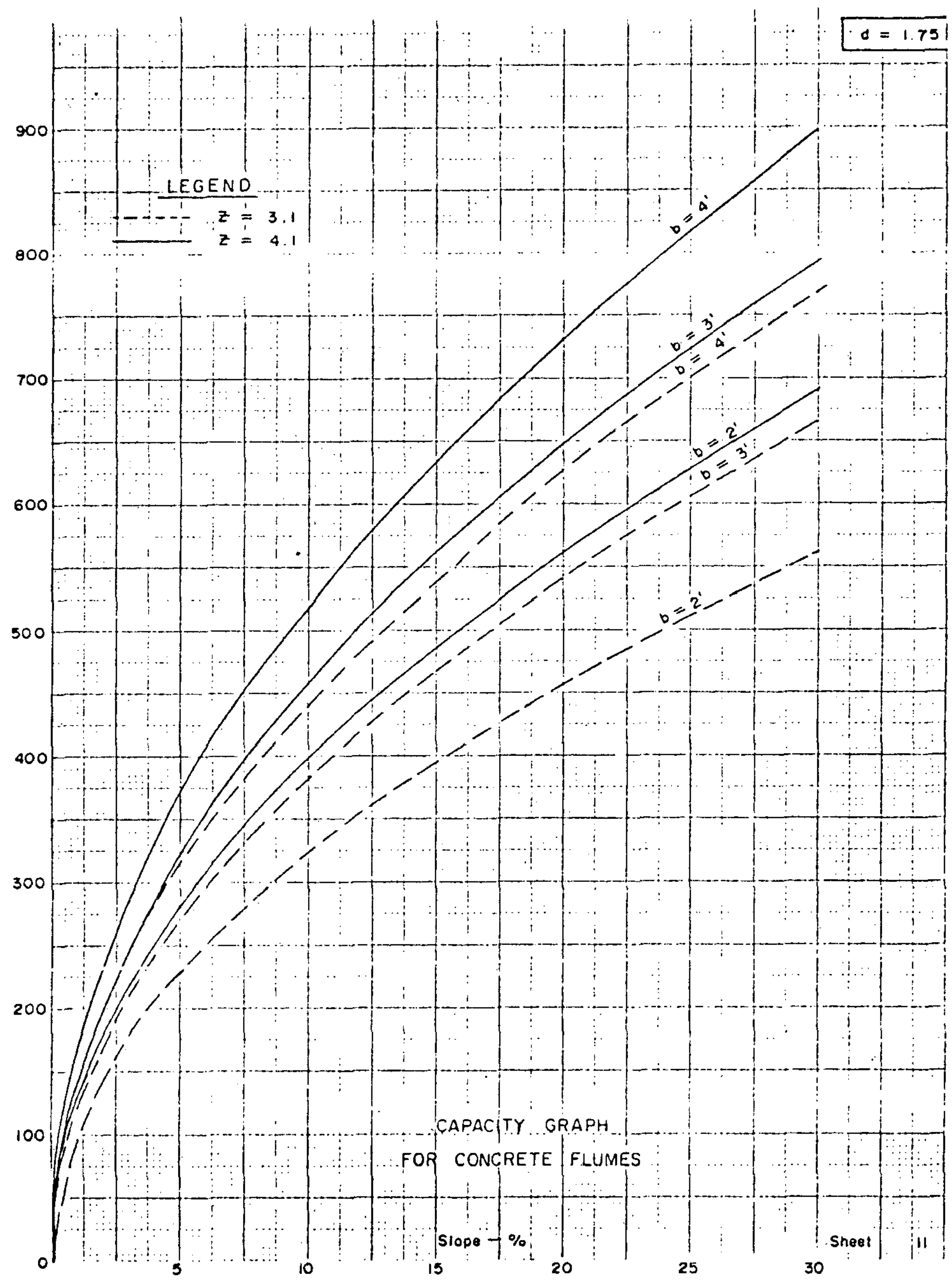
Source: U.S. Department of Agriculture, Soil Conservation Service, State Design Unit, Auburn, Alabama.

Figure 4-39. Capacity Graph For Concrete Flumes.



Source: U.S. Department of Agriculture, Soil Conservation Service, State Design Unit, Auburn, Alabama.

Figure 4-40. Capacity Graph For Concrete Flumes.



Source: U.S. Department of Agriculture, Soil Conservation Service, State Planning Unit, Auburn, Alabama.

either critical gradient or excessive velocities.

The critical gradients for the shapes band together in a narrow range. This range is from approximately 0.005 ft/ft for design depth of 1.75 feet to 0.008 ft/ft at design depths of 0.5 feet. There is a smaller variance with respect to width. For example, in the category with design, $d = 0.5$ and $z = 1:1$, s_c varies from 0.007 ft/ft at $b = 4$ to 0.008 ft/ft at $b = 1$. Because practically all gully flume applications are on land steeper than 1 percent (0.01 ft/ft), critical gradient has little significance. Perhaps the most significant point is that nearly all flumes are designed for greater than critical, or super critical, velocities.

Among the eleven flume capacity curves only Figure 4-30 is usable throughout its entire range because of velocity limitations. It should be obvious that wider, very shallow flumes offer possible solutions, though they are not economical with materials. The following generalities will eliminate some wasted trials.

1) The curves for depths of 0.75 offer possible solutions up to a land slope of about 8 percent on the upper curves and to about 12 percent on the lower curves.

2) The corresponding limits for the 1.0 foot depth curve are from 5 percent at higher capacities to 8 percent at lower ones.

3) The stringent 10 ft/sec restriction limits solutions on

the curves for d = 1.25 ft. to bottom gradients less than 3 percent.

Critical gradient for a flume can be calculated using the following formula:

$$S_c = \frac{14.56n^2 d_m}{r^{4/3}} \tag{4-3}$$

where d_m = mean depth, $\frac{a}{T}$, feet

T = Top with, feet

a = flow cross section, sq. ft.

r = hydraulic radius.

Trials can be checked against allowable design velocities using the formula:

$$v = \frac{Q}{a} \tag{4-4}$$

The flow cross section of a trapezoidal flume is determined by the formula:

$$a = bd + Zd \tag{4-5}$$

Energy Dissipation

The need for energy dissipation varies radically as drainage area increases. The energy dissipation required for small grade control structures--those designed to pass along estimated peak inflow without retarding it--is significantly different from energy dissipation required for a large reservoir with the same estimated peak rate of outflow. A flume designed for a peak rate of 100 c.f.s. will likely experience relatively few hours of flow in excess of 75 c.f.s. in its entire life, while a small reservoir spillway designed for a maximum of 100 c.f.s. may experience many hours each year at more than 75 percent of its capacity. The difference is that in the case of the reservoir, runoff is stored and the rate of outflow is reduced to a more level rate below the inflow rate.

The preceding paragraph is not intended to diminish the truth that water flowing at a super-critical velocity is highly erosive, even if the flow is of short duration. Rather, it is offered as a feeble explanation of why the system outlined in subsequent paragraphs seems to work. The system does not have the unanimous approval of Soil Conservation Service.

The most frequently used method in Alabama of dissipating energy at the termination of flumes has been an attempt to force development of a "scour hole." Especially in low cohesion material, turning the flume down into the ground tends to blow a hole. The hole does not always develop. When it does develop, it is a little unsightly and needs vegetative treatment.

The "scour hole" technique will not work in every situation. A flume cannot be terminated unless the disposal area will serve as a low velocity, erosion-free disposal area. Usually, termination is in the "flood plain" or flat portion of a valley. The technique depends, very heavily, on the capacity of the soils in the disposal area to support a thriving colony of vegetation. In areas where this behavior cannot be expected--in sterile sands of a gully floor, for example--there is little hope for success and some other technique may be necessary.

A recent review by the writer of flumes which has must weathered a 100-year storm reinforced belief that this technique is sound. Scour holes meeting the criteria of the previous paragraph experienced no wear. Their stable dimensions were about twice as wide as the flume top width and three times as long as this width. A riprap-lined basin of similar dimensions would likely assure stability in worse soils, but this remains to be researched.

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CHAPTER V

EVALUATING GULLY ADVANCE

Any land user might wonder, as he ponders his own gully problem, just how fast it is likely to move in the future or how much land he is going to lose. A county commissioner is interested in knowing how long it will be until a particular gully will endanger a highway. A subdivision developer is interested in knowing when the houses in his development will begin to fall into a rapidly moving gully. The answers to questions like these can become the basis for important economic decisions, often without a detailed analysis. The answers can never be precise. However, this chapter presents techniques for making reasonable long range predictions of gully advancement and suggests a reasonable philosophy relative to short term advance. It also briefly discusses the damages that will accrue.

Rate of Headward Advance

When a gully is but a hundred feet, or even a hundred yards, from a crucial target, it may indeed be too late to ask how long it will take for the gully to reach the target. If the gully is anywhere in the Coastal Plain, the smart-sounding but honest answer is, "not very long." When a gully is very close to causing a crucial situation, time is very important, and the answer should be based on how the worst gullies in the area have behaved. It is very common for a gully to advance 150 feet in a given year, though not necessarily every year. An advance of 300 feet per year has been reported to the writer in casual conversation, and he has no reason to doubt the integrity of the reports. Perhaps of greater significance is the fact that a rain in the 25 to 100 year category is known to have caused wholesale movements of 30 to 100 feet on a variety of gullies in south Alabama on April 10-11, 1975. It is the possibility of things like this happening that often lends an air of urgency to the situation when a gully is near a high value target. Unfortunately, this is often when the conservationist is brought into the picture for the first time.

Fortunately, not every situation is so urgent, and there is time to breathe before estimating rate of advance. Soil Conservation Service has adopted a relatively simple technique for predicting rate of advance (1). The technique, empirically derived, presumes advance to be related primarily to drainage area above the headcut and to run-off-producing rainfall. The relationship of the variables is expressed in Equation 5-1.

$$R = 1.5\,(W)^{.46}(P_{0.5})^{.20} \tag{5-1}$$

R = rate of headward advance, feet/year

W = average drainage area above the headcut during gully development, acres

$P_{0.5}$ = average annual summation of 24 hour rainfalls greater than 0.5 inch during gully development, inches

The formula ignores a number of factors which significantly affect rate of advance. This limitation can be partly overcome by relating future rate of advance to historical rate of advance for the same gully. In order to do this an expression was written for the ratio of future to past rate and solved for future rate. This results in the following formula:

$$R_f = R_p\,(A)^{.46}\,(P)^{.20} \tag{5-2}$$

where:

R = future annual rate of advance, feet/year

R_p = past (Measured) annual rate of gully advance, feet/year

A = the ratio of W_f, the average drainage of a particular upstream reach during an unknown period of advance, to W_p, the average drainage area of the reach through which the gully has moved

P = ratio of P_f, the expected long term average summation of annual inches of rain from 24 hour rainfalls of 0.5 inch or greater, to P_p, the average annual inches of rain from 24 hour rainfalls of 0.5 inch or more for the known development period of the gully, if less than 10 years.

The past rate of advance can best be determined from comparison of old and current aerial photography, which is customarily dated. Interview is less reliable.

Rainfall during the development period must be taken from climatological data. Presumed future rainfall is based on Figure 5-1. When the old gully reach required more than 10 years for development, P is assumed equal to 1, unless an unusual weather cycle has influenced development. It should be apparent that one can speculate that in a wet year rainfall may exceed normal by as much as 50 percent. Thus, it is possible to speculate with the formula on what a bad year might bring. Values of $P^{0.20}$ and $A^{0.46}$ may be taken from Figures 5-2 and 5-3 respectively.

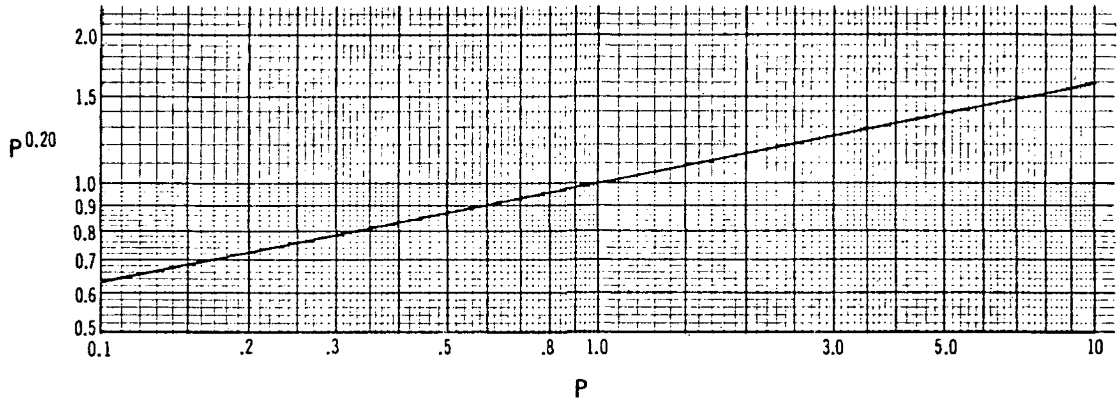
The average drainage area figure for the old portion of the gully is the average of the drainage at the beginning of the development period and the drainage area at the end of the development period. The same concept applies to the average future drainage area. If the rate of development between two points, A and B, is sought, the drainage areas above points A and B are averaged. Reaches are usually selected at points where tributary drainage areas enter the main watercourse so that drainage areas will be more definite. Establishing reaches at all points where there are major drainage area changes adds refinement to the technique.

After a rate of advance is predicted, it is simply multiplied by the length of the reach in question to arrive at an estimated

Figure 5-1. Average Annual Inches of Rainfall From 24 Hour Rains of 0.5 Inch or Greater.

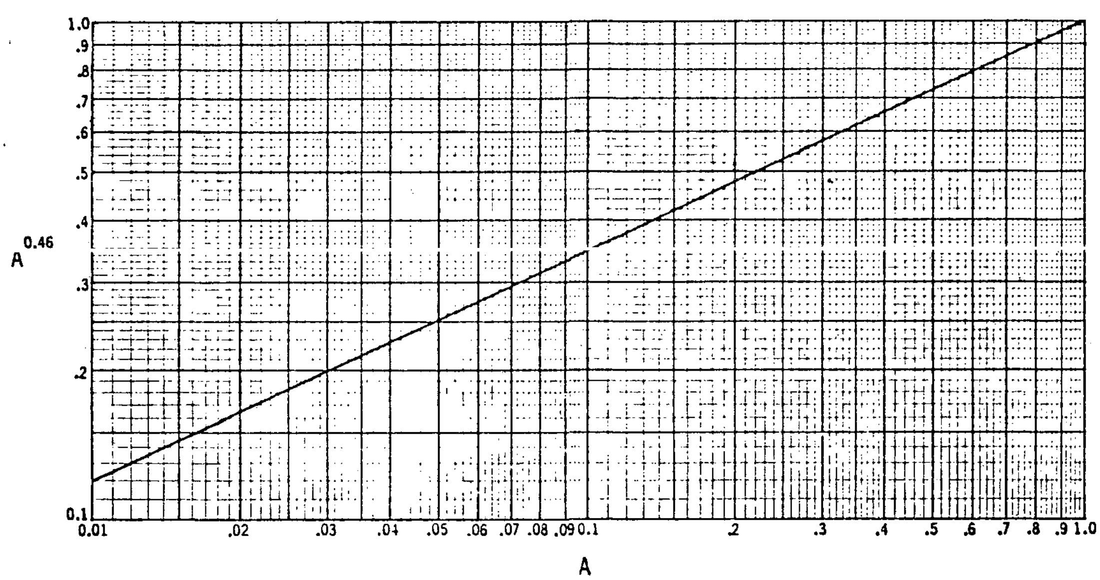
Source: U.S. Department of Agriculture, Soil Conservation Service, Technical Release No. 32, Procedure for Determining Rates of Land Damage, Land Depreciation and Volume of Sediment Produced by Gully Erosion, July, 1966, p.7.

Figure 5-2. Graph For Obtaining the 0.20 Power of Ratio P.



Source: U.S. Department of Agriculture, Soil Conservation Service, Technical Release No. 32, Procedure for Determining Rates of Land Damage, Land Depreciation and Volume of Sediment Produced by Gully Erosion, July 1966, p. 8.

Figure 5-3. Graph for Obtaining the 0.46 Power of Ratio A.



Source: U.S. Department of Agriculture, Soil Conservation Service, Technical Release No. 32, Procedure for Determining Rates of Land Damage, Land Depreciation and Volume of Sediment Produced by Gully Erosion, July 1966, p. 6.

time required for advance through the reach. The technique can be used for predicting advance up tributary drainage areas, utilizing R_p from the main watercourse.

The degree of accuracy of this technique will depend on variation in geologic material and conditions encountered. Experience in an area, particularly with variation in rate due to changes in surface material, will help in evaluation of the formula prediction. Usually it will only be possible to say that the predicted rate is too high or too low. Further, refinement would be unwarranted.

Certain factors have strong influence on gully behavior, and they should serve as keys in trying to decide whether estimated rate of advance (R_f) is too high or too low. Change in materials is probably most significant. Only changes in surface soils may be readily evaluated, though subsurface material is equally important. Radical changes in watershed land use during the life of the gully probably causes nearly as much error in long-term estimates as do soil differences. As runoff production decreases, rate of gully development decreases. Thus, the vegetative factors which affect runoff (Chapter I) are important in evaluating the accuracy of a predicted rate. Finally, it is generally accepted, but not well documented that when a gully intersects the water table, its rate of advance is likely to increase due to continuous slumping at the base of the headcut. Since most Alabama gullies intersect the water table rather early in their development, this may only be an occasional consideration.

There are other approaches to estimating rate of gully advance (2). It is not surprising that a different analysis of the data which produced equation 5-1 gave other relationships which satisfied tests for statistical significance. Equation 5-3 is such a relationship (3).

$$L_R = 0.15 \cdot a^{.49} s^{.14} p^{.74} E \qquad (5\text{-}3)$$

In the formula:

L_R = gully advance, feet

a = drainage area above the headcut, acres

s = approach gradient of waterway over headcut (percent)

p = summation of rainfall from 24-hour rains greater than 0.5 inch. Any period of rainfall records may be used. This sets the time period for L_R. By using one year's duration or using an average annual figure, L_R can be made into an annual rate.

E = clay content, as a percentage, of the soil through which the gully is advancing (clay = 0.005 mm or finer).

This formula was developed from relatively generalized data, including some from Dale County, Alabama. It is included because of its general nature. It is possible to make a rough evaluation of the formula using Figure 5-1 to determine rainfall and county soil survey information to supply the remaining factors.

The relationship between headward movement and clay content, E, calls attention to itself. This is because resistance to direct erosion is expected to increase with increased clay content, yet the formula seems to indicate the opposite. This apperently is accounted for in the observation that most headward advance is likely to be due to slumping of soil blocks (3). Shrinkage cracks, which relate to clay content, apparently are an underlying cause in this behavior.

Lateral Development of Gullies

When gullies develop in materials that are not highly erodible, lateral development tends to be nearly complete as the gully advances up-gradient. In easily eroded material, head cutting is so rapid that gully walls are often vertical. This is especially true where moderately resistant soil is underlain by highly erodible soil. Regardless of their initial inclination, the walls of the gully will succumb to added erosion. The steeper walls will experience various forms of mass-wasting (4). (Mass wasting is a collective term for a variety of types of crustal movements under the direct pull of gravity--various types of earth slides, flow, slump, and creep.) Ultimately, the walls will tend to flatten to the same inclinations witnessed in more mature portions of the surrounding countryside. This will take a relatively long while, and man can in some degree intervene. It will not take forever. Thus, observed valley wall inclinations in the vicinity of a gully may be used to estimate the surface area that will eventually be directly damaged by the gully.

Direct observations of the relationship between depth and top width will provide good information on shorter term land consumption by gullies. Care must be taken to relate material in the gully to different dimensional relationships. On a local basis, such carefully made observations offer the best means of estimating direct loss of land to gullies. Even the best estimate is likely to be very rough, because the effect of many small tributaries tends to get left out of estimates.

In the absence of local observations, two general observations will be of at least limited benefit.

1) Gullies advancing through cohesive material tend to have a width about three times their depth.

2) Gullies in cohesionless materials are about 1.75 times as wide as they are deep.

Evaluating Damage

Damage due to gullying accrues both at the site of gullying and away from the gully. Each category of damage lends itself in varying degrees to rational economic analysis. As a generality, cost of preventing gully growth should be repaid by benefits experienced during the life of the preventative measures. Cost in the sense used here normally includes interest which could have been earned with the capital, if it had been invested in some other manner. This approach is seldom followed in strictness by an individual. Intangible values often outweigh tangible ones to an individual. The pure economic approach must be applied in most situations where public funding is involved to establish sound investment of public monies. This section will treat some of the generalities of damage evaluation, leaving detailed analysis to the <u>SCS Economics Guide</u> (4) and various texts on welfare economics. When shown where the damages are expected, the individual land-user can often apply his own cost factors with greater meaning than any well-meaning adviser could hope to do.

Land Damage

Damage at the site of the gully is broadly typed as land damage. Land which is consumed by the gully constitutes most of this type of damage. Such damage is generally total and irreversible. The value of the land is diminished for all times. It is the irreversible aspect that makes it difficult to use traditional economic analysis without prejudice.

It should be clear that land within a gully usually has some residual economic value. Literally thousands of acres of gullies have been converted profitably to timber production. Many of the gullies in south Alabama are so severe, however, that any attempt at timber harvest would very likely reactivate the gully.

Under the broad heading of land damage is included damage to fixed improvements. These range from fences to hospitals. It should be obvious that many types of fixed improvement damage carry difficult to evaluate domino effects. For example, when a road is severed one must add to repair cost the cost in time, mileage, and inconvenience of detours. (And there may not be a detour available.) When a communications cable breaks, the cost in lost service may be thousands of dollars per minute, but the underlying costs are completely inaccessible.

Offsite Costs

The most apparent offsite costs are costs which accrue to land adjacent to a gully. This land tends to depreciate in value because of the inconvenience and added cost of using the land. It is hazardous to try to pasture land adjacent to a gully, for example, without fencing the gully. Cows wander over the edge and die suddenly, but they also wander in only to become bogged hopelessly in "quick" bottom and die slowly from fear and fatigue. With fencing costs approaching a dollar per foot, this is becoming a substantial consideration.

Gullies tend to disrupt fields and make them much harder to farm. Small portions of fields are often isolated or set apart in such a manner that they must be abandoned. Fringes adjacent to the gully for turning areas or areas considered unsafe for heavy tractors add to the inventory of idle, non-productive land. Water management becomes much more difficult once a gully has entered a farm. Where grassed waterways were once adequate, underground outlet systems are needed to deliver runoff to a safe disposal point.

Gullies do not disrupt land so completely that urban development is impossible. They simple depreciate the land by an amount equal to the cost of filling existing gullies and installing adequate structural control to prevent recurrence. If there is an alternate, this is sufficient deterrent to delay or prevent urban development indefinitely. Unfortunately, it is often true that only the developer recognizes the hazard of gullies in an urban area. He hastily throws his development together and gets rid of the "hot potato" before it is too late. To be fair, sometimes the developer doesn't even recognize the hazards.

Countrywide, sediment damage is a very high value of off-site damage. The repository for the sediment determines the value.

It is by far the hardest to put realistic dollar values on. It is easy to see that it costs a dollar a ton to dredge sediment or that productive value of certain land is virtually zero because of deep sand-gravel deposits. Less apparent but equally real are biologic losses. An individual land user will seldom interest himself beyond the generalities of sediment damage.

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